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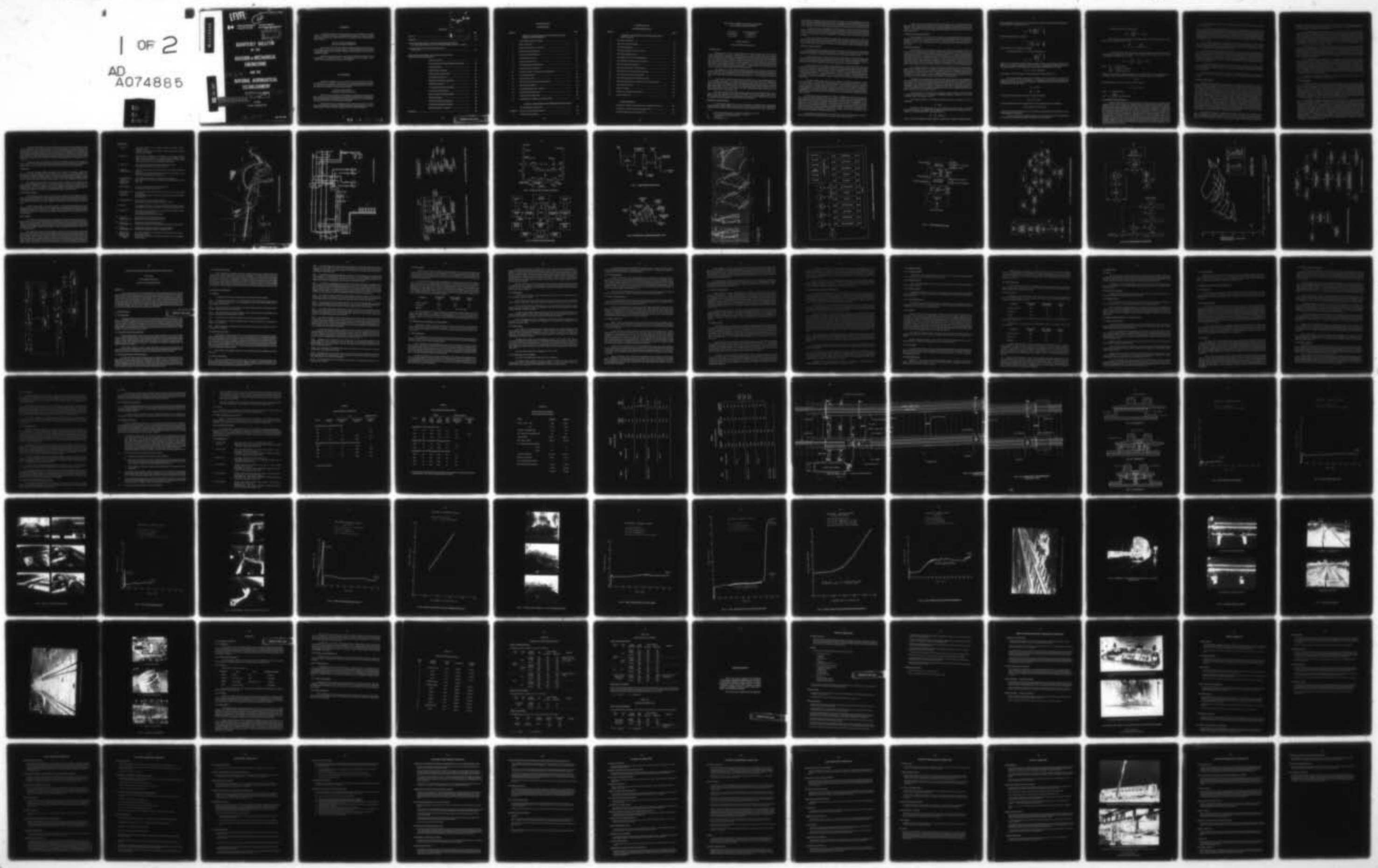

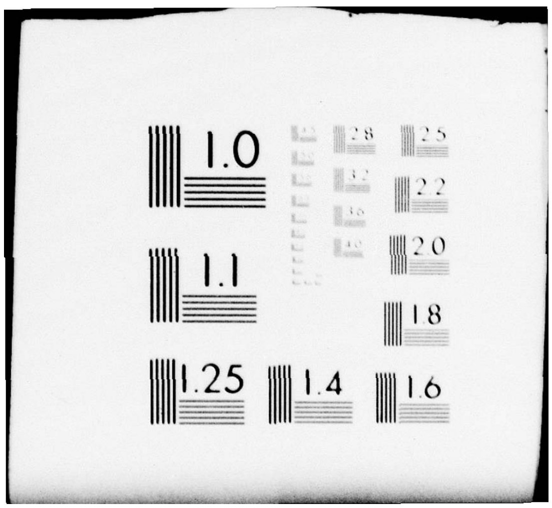
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FOREWORD

The Quarterly Bulletin is designed primarily for the information of Canadian industry, universities, and government departments and agencies. It provides a regular review of the interests and current activities of two Divisions of the National Research Council Canada:

Division of Mechanical Engineering
National Aeronautical Establishment

Some of the work of the two Divisions comprises classified projects that may not be freely reported and contractual projects of limited general interest. Other work, not generally reported herein, includes calibrations, routine analyses and the testing of proprietary products.

Comments or enquiries relating to any matter published in this Bulletin should be addressed to: *DME/NAE Bulletin, National Research Council Canada, Ottawa, Ontario, K1A 0R6*, mentioning the number of the Bulletin.

AVANT-PROPOS

Le Bulletin trimestriel est conçu en premier lieu pour l'information de l'industrie Canadienne, des universités, des agences et des départements gouvernementaux. Il fournit une revue régulière des intérêts et des activités actuelles auxquels se consacrent deux Divisions du Conseil national de recherches Canada:

Division de génie mécanique
Établissement aéronautique national

Quelques uns des travaux des deux Divisions comprennent des projets classifiés qu'on ne peut pas rapporter librement et des projets contractuels d'un intérêt général limité. D'autres travaux, non rapportés ci-après dans l'ensemble, incluent des étalonnages, des analyses de routine, et l'essai de produits de spécialité.

Veuillez adresser tout commentaire et toute question ayant rapport à un sujet quelconque publié dans ce Bulletin à: *DME/NAE Bulletin, Conseil national de recherches Canada, Ottawa, Ontario, K1A 0R6*, en faisant mention du numéro du Bulletin.

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DESIGN OF GAS PIPELINE STATION CONTROLLER USING HYBRID COMPUTER MODELS†

R.E. Gagne*   G.F. Moellenkamp****
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INTRODUCTION

Natural gas has become a very important form of energy in North America, and vast networks of pipelines have been built to transport this gas to a continent wide market. The complexity of the networks and the advantages of high pumping pressures have required considerable engineering effort to ensure safe and reliable operation. When the lines and pumping facilities were first installed, they were designed using the available technology in the light of the current gas costs. As the market grew, more loops were added, and new pumping equipment in the form of gas turbines became available and were used. This has resulted in very complex pumping systems involving large blocks of power, with widely differing operating characteristics, to create operational and control problems unique to multi-loop, multi-compressor gas transmission systems.

One example of a control problem results from operation of compressors in parallel. The problem is that one of the operating units can gradually pump increasingly more flow than the others. The "starved" units then run gradually closer to their surge limits until an emergency shutdown of that unit is required. This results in a further loading of the hogging unit until it reaches an operating limit.

Control of these multi-unit pumping stations clearly requires control strategies which, in the first instance, allow each of the units to operate with the other units in various configurations. The control should also attempt to optimize the operation of the station with respect to fuel usage where the advantage can be appreciated by noting that TransCanada PipeLines themselves consumed $48.5 million worth of fuel in 1976. Thus even small improvements in station efficiency can reap large returns. Better station control together with other operational and design improvements can play an important part in lowering fuel costs.

This paper describes a minicomputer based controller which was designed for gas pipeline station control. The controller has, to date, been installed in the 10 most complex stations of the TCPL network. The paper reviews the development of the controller and highlights the role played by computer models and simulation techniques during its development.

HISTORICAL BACKGROUND

In 1967, TransCanada PipeLines Ltd. were operating a 3,000-mile pipeline transporting natural gas from Alberta to Quebec. At that time it was the largest pipeline in the world with 48 compressor stations located at 50 to 60-mile intervals along the route shown in Figure 1. By then the

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† Presented at the Canadian Conference on Automatic Control, McGill University, May 1979.
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system had been expanded to four loops and the first station at the Alberta/Saskatchewan border incorporated six reciprocating compressors and five centrifugal compressors representing more than 75,000 installed horsepower. Station control was accomplished by an operator who monitored the station requirements and each unit and made adjustments or brought units on or off line as required.

At that time a group of engineers from TransCanada, the National Research Council and Graham F. Crate Ltd. met to consider station control problems. It was quickly recognized that development of new station controls must be evolutionary in nature, in order that each step could be checked out in the field to insure a safe transition to new hardware and associated new operational procedures.

Two key decisions were made at the beginning of the project. First, a review of the functional requirements for station control was required in order to devise an appropriate control policy. The second and equally important decision was to develop computer models of the stations in order that simulated trials could be used to evaluate new control ideas and checkout resulting hardware.

PIPELINE CONTROL POLICY

Pipeline control is concerned with two main operations. At a strategic level, overall pipeline considerations establish station setpoints appropriate to current delivery requirements and available station units. Each station must then control its machines to achieve these station setpoints.

In the TCPL network, central control is from the main offices in Toronto. Real time data from the stations is telemetered to the gas control center where a Gas Control Operator decides how best to run the pipeline. An IBM 370/148 is used to run static models of the pipeline in order to predict the effect of any changes to the station setpoints as an aid to this decision process.

At the station level, the control of the pumping units is complicated by the wide variety of machinery types which can exist. Each pumping unit can have different pressure and horsepower limits from its neighbours and yet may have to operate in parallel with them. Each can have a number of other units in series or parallel, and each must be controlled so as to contribute positively to the overall station performance. A typical station layout is shown in Figure 2. This particular station incorporates 29 valves; each combination of valve setting represents another station state which in turn affects overall station performance. Figure 3 is an overview of the station controller task for this same station.

The station control policy arrived at can be viewed as a hierarchical arrangement of tasks as shown in Figure 4. The most basic control parameter is unit speed and, at the lowest level, the unit control closes the governor loop on each unit's speed control. Each speed setpoint is established by the next level of controller task which attempts to control station throughput in response to changing demands. For parallel operation, a decision must be made as to how the unit's setpoint will be manipulated to achieve the new station throughput. This decision depends on what fraction of the station flow is to be contributed by each unit and how well that unit is doing in carrying its required share of this flow.

The flow split among the units of the station is established in the best way by the next level of task, the station optimizer. This task monitors the current station status and determines if some different flow split will achieve the current station condition with less expenditure of fuel. That this may be true is due to the different efficiencies of each unit and to the dependence of unit efficiency on current operating conditions. Unit performance information is observed from the next higher level of the hierarchy in the form of computer models. The optimizer makes use of these models to search for a better load sharing split. Model validity is maintained by continually monitoring all unit behaviour, validating the measurements through a sophisticated combination of gas path analysis and trending of key variables for each unit.

The telemetry task provides for the communication with the central pipeline control by sending the status information required and receiving the current station objectives.

Finally, overseeing all of these tasks is the station operator. As does an airline pilot during flight, the station operator interacts with the system by monitoring activity, making use of any of the automatic modes available and providing the overriding judgement necessary for effective station control. He is aided by an information display task which provides him with convenient access to the status of the system.

CONTROL SYSTEM DEVELOPMENT

The development of new controls for as complex and as potentially dangerous a system as a gas pipeline is best done in a test environment which is very tolerant. Before any new controller was installed in the field it was considered cost effective to ship the controller to the computer model of the station it was to control, and perform some of the commissioning work using this dynamic computer model.

COMPONENT MODELS

Models appropriate to the design of a station control system were required, which in turn dictated the form of the models used. Dynamic models were required for all of the mechanical components such as compressor shafts, throttle actuators, and pipeline flows; steady-state models were considered adequate for the compressors and the thermodynamics in the station yardpiping. Model development proceeded by obtaining descriptions of the components found in a station. These included elbows, tees, orifices, scrubbers, as well as the valves, engines and compressors. With these component models, a particular station configuration could be put together in much the same way as the station itself was built. These station models were used extensively in the design of the unit and station control tasks of the control system, as well as the checkout of the control hardware itself.

As an example, Figure 5 is a layout of the component modules used to model one compressor plant of TCPL's station 17, and Figure 6 indicates the general solution scheme on the NRC hybrid computer. All dynamics were solved on the analogue computer, and algebraic and steady-state thermodynamic relations were solved in the digital computer. Since the proposed controller was eventually to be a mini-computer, its logic was naturally modeled primarily in the digital computer, and ultimately was replaced with the actual control computer for final checkout.

Although the models used are described elsewhere (Refs. 3 and 6) the main pumping unit will be described here as this will illustrate the level of detail required and give some insight into the requirements of the unit monitoring task which came much later in the project. Figure 7 is a schematic diagram of a natural gas compressor pumping unit. A gas generator, consisting of compressor, combustion chamber and turbine, produces compressed hot gas. This is expanded through the free power turbine which drives the natural gas compressor as its load. Fuel is obtained directly from the pipeline or from some other available fuel source.

To model this unit, consider first the natural gas compressor. Figure 8 indicates the kind of measurement data which can be obtained for centrifugal compressors, and Figure 9 is the actual compressor "wheel" flow maps for station 2.

For modeling purposes, the compressor rotational speed can be expressed as a ratio of design speed

$$R = N/N_d$$

Similarly, the flow through the unit can be normalized, usually with respect to standard atmospheric conditions. The relation between adiabatic head and flow for a compressor can be expressed as a second order polynomial in both speed and flow.

$$H_d = aQ^2 + bQR + cR^2$$

where a, b and c are constants for a given compressor in a given state of health. The adiabatic head, H_d,

for the compressor is related to the basic thermodynamic parameters of pressure P, and temperature T on the input ($P_1 T_1$) and output ($P_o T_o$) by

$$H_d = \frac{ZRT_1 \gamma}{\gamma - 1}\left\{\left(\frac{P_o}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\}$$

where the compressibility, Z, is given by

$$Z = \frac{1}{1 + \frac{P_1}{T_1}\left\{m + n\left(\frac{1}{T_1} - 1\right)\right\}}$$

where m and n are the constants for natural gas.

The temperature rise, ($T_o - T_1$), across the compressor is

$$(T_o - T_1) = \frac{T_1\left\{\left(\frac{P_o}{P_1}\right)^{\frac{\gamma-1}{\gamma}} - 1\right\}}{E_a}$$

where E_a is the compressor's adiabatic efficiency which is a function of operating point as shown in Figure 8. It is possible to replot these efficiency contours as a temperature rise and it was found that this could be adequately represented, again, as a second order polynomial of flow and speed

$$(T_o - T_1) = dQ^2 + eQR + fR^2$$

where, again d, e and f are constant for a given compressor in a given state of health.

For a given adiabatic head across the compressor, the flow is limited on one side by the maximum horsepower, (or more specifically by the maximum torque which the compressor can handle), and the other side by a flow breakdown or stall condition called surge. These limits were expressed as linear functions of flow

$$Q_{sl} = g + hH_d$$

$$Q_{hp} = r + sHd$$

The compressor is also restricted to operate over a given speed range

$$N_{min} \leqslant N \leqslant N_{max}$$

Thus the compressor model can be described by the above equations and a set of parameters

$$(a,b,c,d,e,f,g,h,r,s,\ N_d,\ N_{min},\ N_{max})$$

where the first 6 parameters will need to be updated from actual measurements made by the unit monitoring task of the controller.

In order to relate the compressor operation to the other components of the pumping unit it is necessary to consider the power that it draws from the driving turbine.

The horsepower required to pump the gas is

$$HP_g = \frac{H_d Q k_1}{33000 \xi_a} \ ; \ k_1 = \text{constant}$$

Since this power must be supplied by the gas generator and delivered through the power turbine, torque requirement of the load is:

$$G_\ell = \frac{HP_g}{N \cdot \eta_{pt}} = \frac{H_d Q k_1}{N \cdot 33000 \cdot \xi_a \cdot \eta_{pt}}$$

The rotational inertia of the gas generator is very small compared to that of the load, hence the steady state relation between fuel burnt and resulting gas generator output power can be used. This information is available as the expression

$$W_{fe} = f_a \sqrt{\frac{T_A}{520.}} \cdot \frac{P_A}{14.696} + f_b \cdot HP_{gg}$$

where W_{fe} = fuel flow input
T_A, P_A = ambient air conditions
HP_{gg} = delivered horsepower

and f_a, f_b are constant for a given gas generator in a given state of health. Thus the gas generator can be defined by these equations and by the parameter set supplied by the unit monitoring task:

$$(f_a, f_b)$$

Finally, rotational speed of the compressor will thus be given by

$$N = \frac{1}{I} \int (G_g - G_\ell)\, dt$$

where I = rotational inertia

and $G_g = \left(\frac{HP_{gg}}{N}\right)$ = delivered torque

CONTROLLER TASK DEFINITION

The first controller task which was addressed by the design team was the compressor station control problem of how to adjust unit setpoints to achieve acceptable behaviour without regard to optimization. The scheme adopted was a parallel control scheme which was based on a 'permissive' principle. Overall station discharge pressure or station flow had to be maintained by requiring each unit to carry its 'fair share' of the flow. If increased or decreased flow is required as determined by the overall station requirements, then each unit on line is monitored to see if it is on a high or low limit, and, if it is capable of responding to a demand change, the actual percentage of flow it is currently delivering is compared to the flow split setpoint for the unit. If increased station flow is requested, then only those units which are delivering less than their required share of this amount are asked to deliver more, and vice-versa. Before any change is actually requested, the station control algorithm weights the request to the responding units in proportion to the ability of each in terms of its rated horsepower. In this way the control action produces the same response regardless of how many and which units are on line.

The unit controls themselves are proportional/integral controls, and have built in overriding action based on limits.

Two versions of this station and unit control were implemented. In keeping with the requirements of an evolutionary design the first version was a hard-wired analogue/relay unit which was specified and built by a manufacturer of control hardware. This unit was subsequently delivered to the NRC in Ottawa and set up to control the station model. Commissioning procedures were designed using the model, and the subsequent installation in the field was completely uneventful. The permissive control scheme had been designed and tested using the computer models, and proved successful in the field.

The second version of the unit and station control involved implementation of the control logic in digital computer hardware. A second station (station 13) was selected for the new controller, and a mini-computer was obtained as the control hardware. Again the station model was used to check out the new hardware before it was installed in the station.

The next step in the evolution was the design of a real time executive operating system for the computer to which the controller tasks could be attached as they were developed. It was required that the operating system and all the data banks for the controller should be specified early in the project, and would become the skeleton on which the specific tasks for a given station could be attached. The design of a new controller for another station would be almost a "fill in the blanks" operation. The operating system developed is known as the IPEX-11 Executive System, and its structure is shown in Figure 10.

An important feature of the controller executive is the ease with which the station operator can design displays of those station parameters he wishes to monitor. This display task was designed to be easily understood and used, and all interactions at the computer console are as free of computerese as possible.

The next station selected for the controller and the IPEX-11 Executive was the most complex station of the line, station 2. Once again this was accomplished using computer models for checkout.

STATION OPTIMIZATION

Having established that station control based on the permissive flow split concept worked, and having provided the digital computer environment necessary for its implementation, the station optimization task was addressed. Up until that time, the flow split had been set by the operator. Any optimizing algorithm would have to be good enough to compete with experienced operators and convince them of its value. Fortunately the rapid rise in fuel costs during this time favoured any scheme which could continuously monitor and update these setpoints in a way which was not possible under manual control. Fuel costs increased almost an order to magnitude during this period. The approach taken for the optimization task is illustrated in Figure 11. Of the units available in the station, some or all of them can be in operation. A particular configuration of units is known as a station mode, and for each possible mode there is a flow split which minimizes the fuel costs for a given station operating condition. The capability of any station mode to deliver the required flow at the current suction and discharge pressures can be checked by computing the minimum and maximum station flows possible for that mode and comparing these values with the station demand. If the demand is within the possible range, that mode is feasible and the optimum flow split can be sought. Figure 12 is the functional flow chart for this process, and Figure 13 is a data and processing module layout for the program produced. The procedure is as follows:

For a given flow split, and a specified station mode, the model of each pumping unit is used to calculate the fuel required to deliver that unit's share of load, and so the total station fuel flow can be obtained. A search strategy based on a pattern search procedure (Ref. 6) was used to adjust the flow split among the units. By computing station fuel at different trial flow splits, the

mininum computed station fuel could be found. This new flow split is then used to adjust controller setpoints on each physical unit. If either demand or station conditions change, this information is processed to produce new optimum control settings.

The optimizing search strategy used is shown in Figure 14. A number of exploratory calculations are done to determine the local shape of the total fuel flow surface, and a direction on this surface is established which holds promise of improvement in fuel performance. Physical constraints such as compressor surge or horsepower limits are included in the total fuel flow surface by adding steep penalty functions which are proportional to the amount by which the constraint is exceeded. In this way the search is directed in promising directions and yet avoids violating constraints. Since the feasibility check ensures the existence of a solution, the procedure of applying penalties to the constraints will direct the search towards this solution.

To illustrate the use of the optimization package, Figure 15 is a plot of the minimum fuel requirements of TCPL station 2 as a function of station mode and flow, for a given suction and discharge pressure. For a given station flow, it can be seen that not all station modes are possible, and of the ones which are, some are better than others. For all six units on line, i.e. mode 13, the worst possible flow split yielding maximum possible fuel costs is also plotted. This gives an indication of the increased costs which are possible unless some attempt is made to "balance" the station, either automatically or manually.

It is clear from the above discussion that the calculated optimum flow split will only be valid if the unit models upon which the calculation is based are accurate and up-to-date. This imposes the requirement that the models be modified as equipment ages, and since the health of any unit is determined from selected measurements, there is the additional requirement of validating the measurements. This requirement also manifests itself in an even more direct way in that the system must be safeguarded against "wild" measurements from station transducers. The optimizing scheme, therefore arranges to check the change in flow split requested from that last used. If the change is excessive, the system automatically reverts to a flow split based on rated horsepower and a message to this effect is sent to the operator's terminal.

The problem of measurement validation is thus important for the system's safety as well as for the accuracy of the optimum flow split calculation.

UNIT MONITORING

The usefulness of the optimizing task is critically dependent on the accuracy of the models used to describe the pumping units. These models must accurately reflect the change in the performance of the units with time, and so can be coupled to an overall engine health monitoring (EHM) activity. As shown in Figure 16, machinery health monitoring involves comparing current measurements with some baseline established when both the instruments and the units were healthy. The health monitoring can be extended to include calculated parameters such as component efficiencies and mass flows which are not directly measurable, and a disagreement with a baseline value can mean that either an instrument has changed or a unit has changed, or both. It was necessary that some mechanism be available to separate instruments from unit deterioration effects.

A measurement validation package, (yet to be implemented in a station) was devised (Ref. 12) as described by Figure 17. The procedure is based on the premise that knowledge of the physical laws governing the various components within a pumping unit, together with a few key measurements, can be used to distinguish between instrumentation errors and degraded pumping equipment. Furthermore the procedure can indicate the degree of degradation and so can be used to update the unit models used for the optimum search scheme. For example a dirty compressor will result in a predictable change in the set of measurements typified by a decrease in efficiency. If the gas path analysis, based on a set of measurements, indicates an increase in efficiency, it is natural to suspect the measurement of some parameter. By means of thermodynamic relations and sensitivity matrices a complete measurement validation scheme was devised to produce reliable data upon which to base assessments of the health of the components with the pumping unit, as well as to update the unit models for the search.

Computer models played a key part in the design and checkout of the measurement validation system. Models such as shown in Figure 18 were put together on the hybrid computer, and specific changes to the unit components and/or errors in the measurements were introduced. The resulting sets of simulated measurement data were analyzed by the validation and monitoring task thus providing known results upon which to test the procedure. The final checkout of the package was performed by TCPL field engineers using actual measurements taken before and after engine service. The procedure was able to identify all changes, and was judged by the field engineers to be a useful tool.

As mentioned, this unit modeling and measurement validation task is yet to be installed on line in a station. At the moment, model update information is reviewed by the station operator who makes the decision as to how and when to update the unit models used by the optimizing task.

HARDWARE

The station computer hardware installed in 1973 in station 13 consisted of a PDP 11/20 with 8K, paper tape and a DEC tape I/O. The interface to the station was via a TCPL designed subsystem with 64 analogue-to-digital channels. Discrete digital I/O was photo-diode isolated on input, and had relay output. This original system has evolved to a 16K PDP 11/05, with 256K fixed head disc, dual cassette tapes, and a CRT/keyboard and printer for the recent installations in other stations.

The hybrid computer used for modeling the station components is the EAI Pacer 600, in the Mechanical Engineering Division of the National Research Council. Total digital capacity is 32K words with 750K discs. Analogue capacity is 60 integrators with associated summers, pots and patchable logic. The converter system is 48 analogue-to-digital and 24 digital-to-analogue channels. All programming was done in Fortran with standard hybrid computer system routines.

COST EFFECTIVENESS

Fuel savings which are a direct result of the new controller have been difficult to access, as the more accurate performance data obtained during the design of them had already resulted in better operating procedures. It has been estimated, however, that this fuel saving is of the order of 1-2% which means that the cost of the controller is recoverable in about two years at current gas prices.

Another major benefit of the project has been the increased understanding of station behaviour and an increased awareness of the contributions of yard piping pressure losses and station operating procedures to fuel costs. These new insights coupled with the effective information handling capabilities provided by the computer have enabled the station operators to run the stations better and more easily.

CONCLUSIONS

The design of station controllers for a gas pipeline has been successfully achieved due, in large measure, to the use of computer modeling and simulation techniques. The use of these computer models of the pumping station components provided the design team with an effective environment to carry out their design work, as well as an effective means of accumulating information about station performance. The hybrid computer implementation of these models also allowed for the check out of the resulting hardware.

This project also illustrates the collaboration possible between government research groups and industry. Development of the computer modeling techniques, and the computer models themselves required access to extensive simulation facilities and other information and skills more readily found in larger research environments such as NRC. Once appropriate models were defined, only those with experience in pipeline operations could direct the simulated trials in support of the actual design activity. Collaboration of this kind, with a computer model accumulating the knowledge and skills of all the team members, was a most effective means of arriving at a good problem solution.

REFERENCES

1. Reid, R.J. — *Compressor Station Control Problems Solution by Hybrid Analog — Digital Computers.* Canadian Gas Association, National Technical Conference, Toronto, November 18-20, 1970.

2. Farmer, F. — *Control Systems Modeling and Simulation of Compressor Stations.* NRC Associate Committee on Automatic Control Workshop, Banff, Alberta, 24-26 October 1973. (Available as NRC Lab. Memo AC-142, Analysis Laboratory, Division of Mechanical Engineering).

3. Gagne, R.E. — *Computer-Aided Design of Gas Pipeline Compressor Stations.* NRC, DME Newsletter Vol. 4, No. 2, June 1974.

4. Farmer, F., Moellenkamp, G. — *A Multi-Purpose Computer Control System for Gas Pipeline Compressor Stations.* IEE Petroleum and Chemical Industry Conference, San Francisco, Calif., September 1974, (IEEE Paper PC1-74-44).

5. Van Blokland, G., Mufti, I.H., MacIsaac, B.D., Gagne, R.E. — *A Fuel Minimization Procedure for Stations of a Gas Pipeline.* NRC, DME Lab. Tech. Report LTR-AN-20, National Research Council, May 1975.

6. Moellenkamp, G. — *Compressor Station Software can be Standardized.* The Oil and Gas Journal, June 9, 1975.

7. Moellenkamp, G.E., Scott, J.N., Farmer, F.H. — *A Compressor Station Mini-Computer System for Control, Monitoring* and Telemetry. 13th World Gas Conference, London, 1976, Internation Gas Union Paper No. IGU/C9-76.

8. Moellenkamp, G.E. — *Mini-Computer Compressor Station Operation.* American Gas Association Conference, Las Vegas, 1976.

9. Reid, R.J. — *The Impact of Fuel Cost on Compressor Station Design and Operation.* 1976 ASME Gas Turbine Conference, New Orleans, 21-25 March 1976.

10. Farmer, F.H. — *Implementing Local Computer Control of Compressor Stations, Installation, Operation and Maintenance.* AGA Transmission Conference, May 1977.

11. Cooke, L.A., Moellenkamp, G.E. — *Saving Fuel at Pipeline Compressor Stations.* Instrumentation Technology, November 1977.

12. Cooke, L.A., Moellenkamp, G.E. — *Energy Conservation with Mini-Computers.* Canadian Gas Association, National Technical Conference, October 1977.

13. Cooke, L.A., Moellenkamp, G.E. — *A Fuel Saving Technique for Pipeline Compressor Stations.* ASME Energy Technology Conference, September 1977.

14. Agrawal, R.K., MacIsaac, B.D., Saravanamuttoo, H.I.H. — *An Analysis Procedure for Valication of On-Site Performance Measurements of Gas Turbines.* ASME Paper 78-GT-152, Gas Turbine Conference, London, England, 9-13 April 1978.

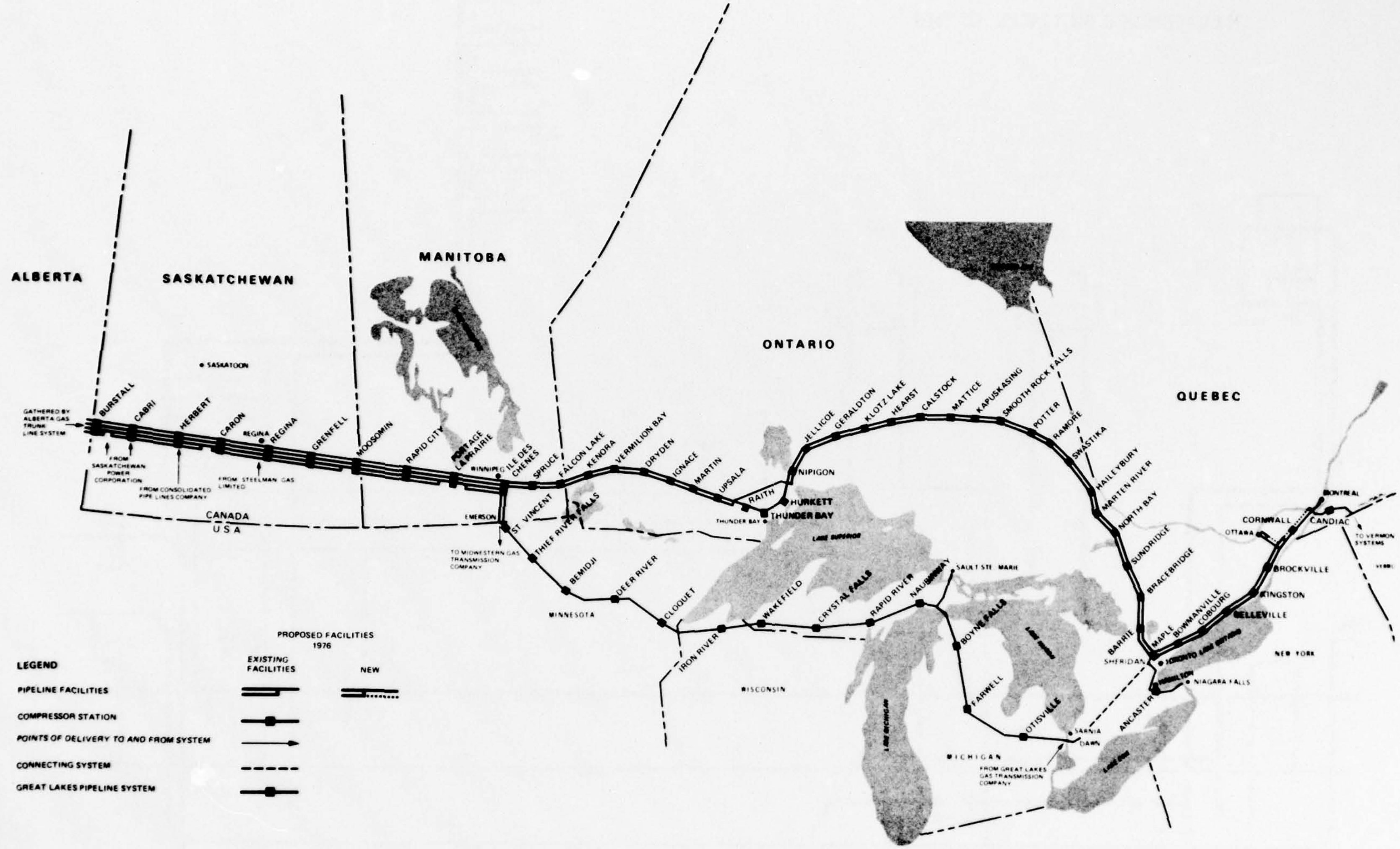


FIG. 1: THE TRANSCANADA PIPELINE NETWORK

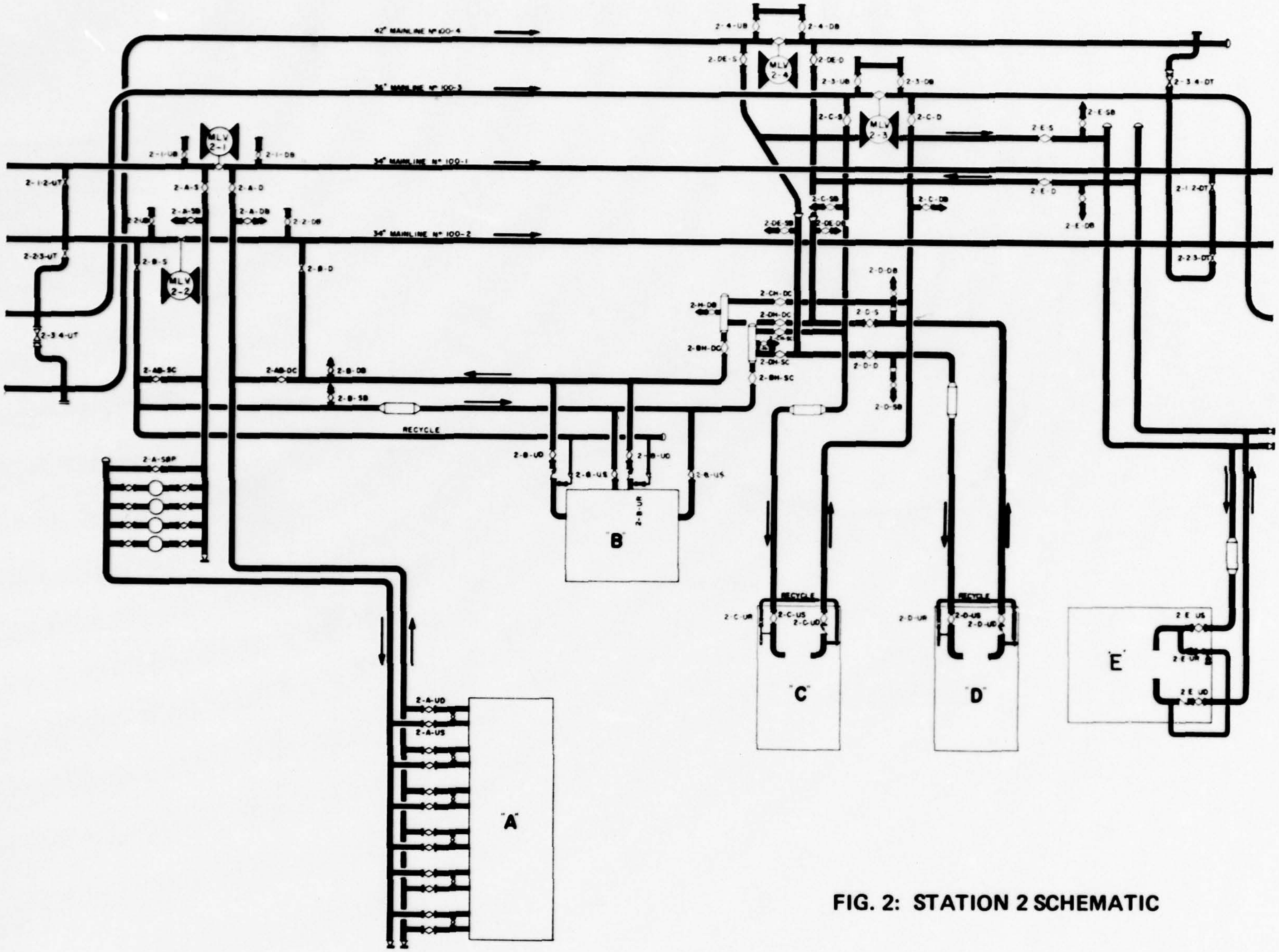


FIG. 2: STATION 2 SCHEMATIC

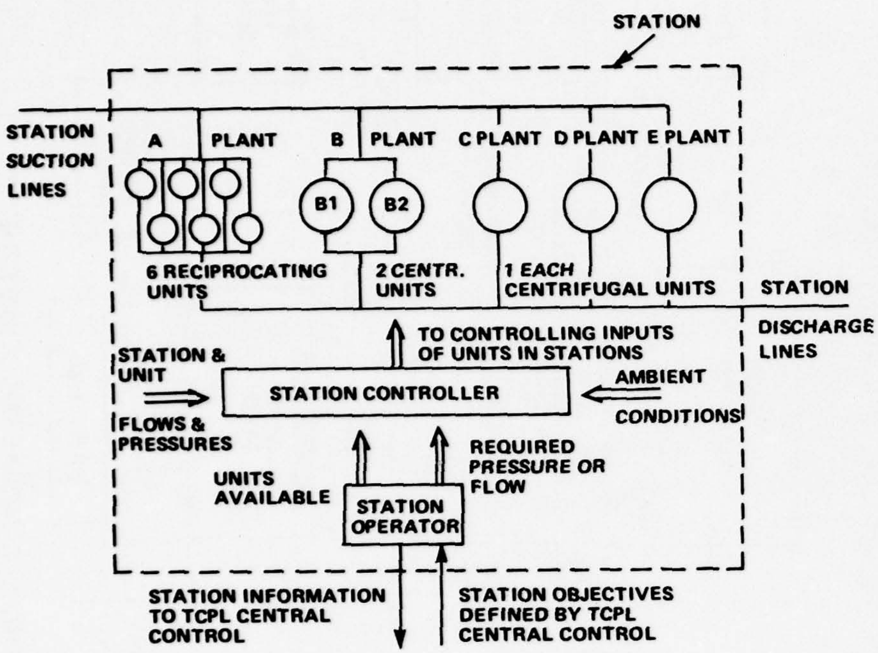


FIG. 3: STATION CONTROL OVERVIEW – STATION 2

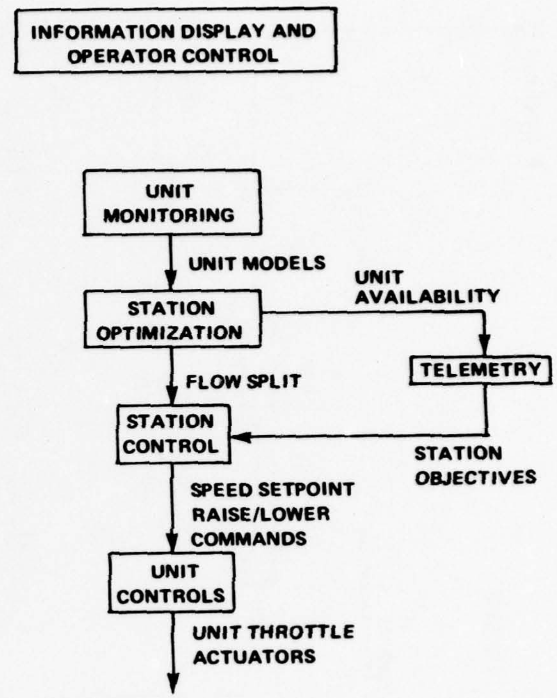


FIG. 4: STATION CONTROL TASK HIERARCHY

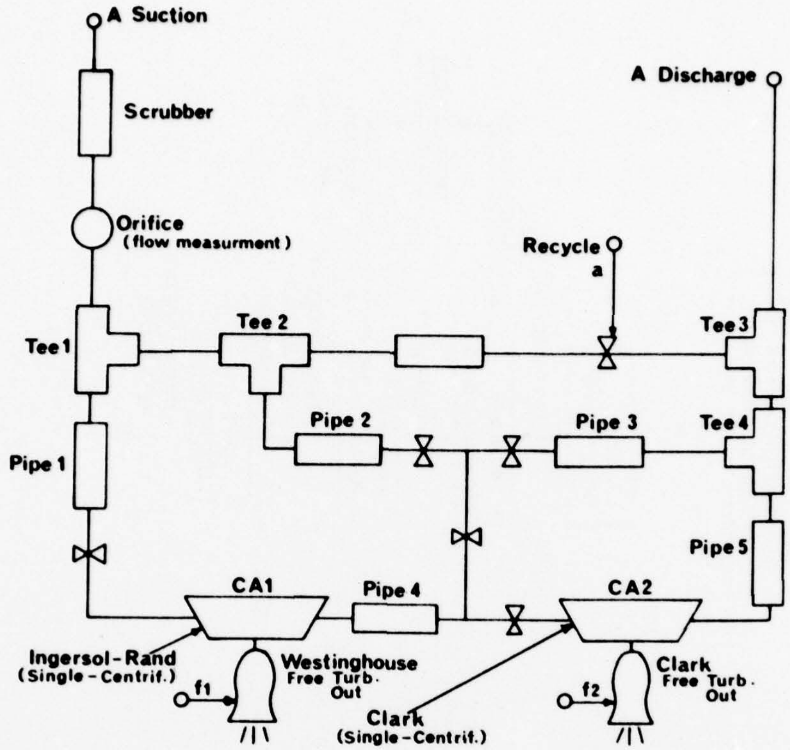


FIG. 5: PLANT LAYOUT-A PLANT STATION 17

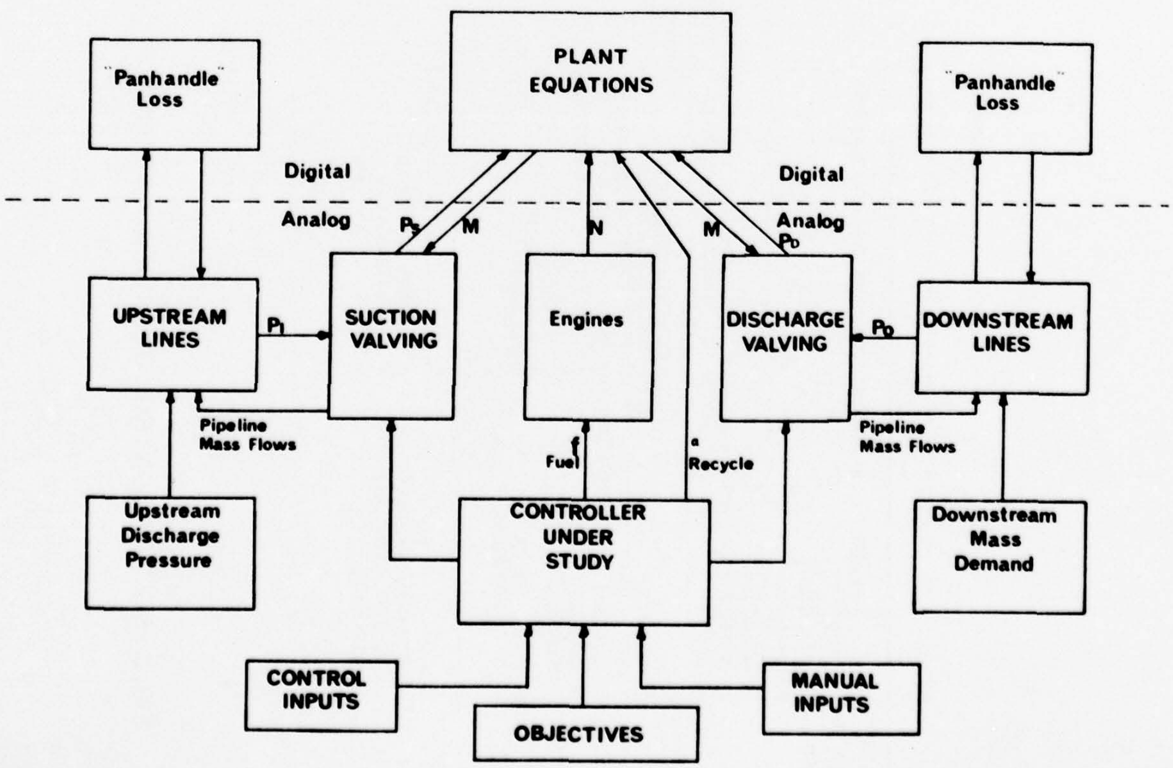


FIG. 6: GENERAL SOLUTION SCHEME

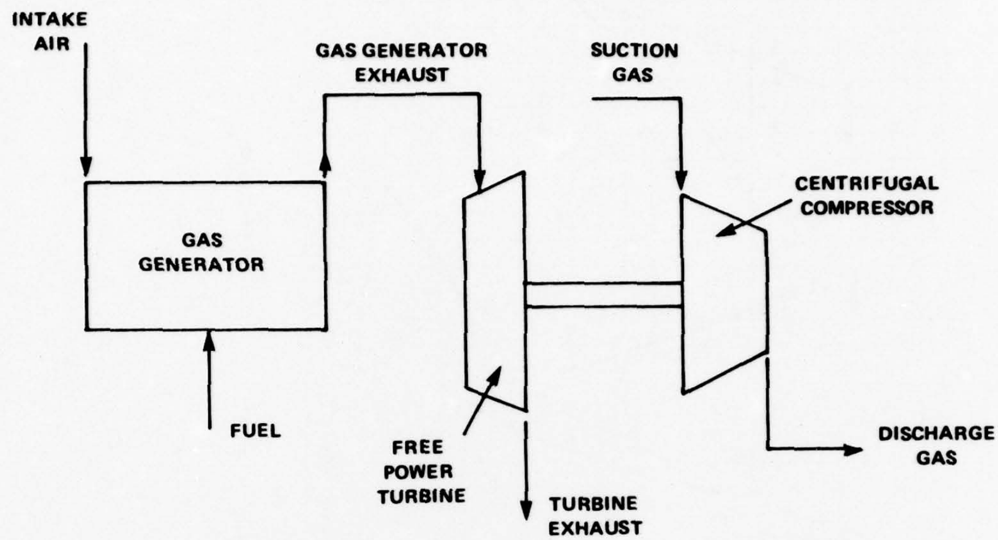


FIG. 7: COMPRESSOR PUMPING UNIT

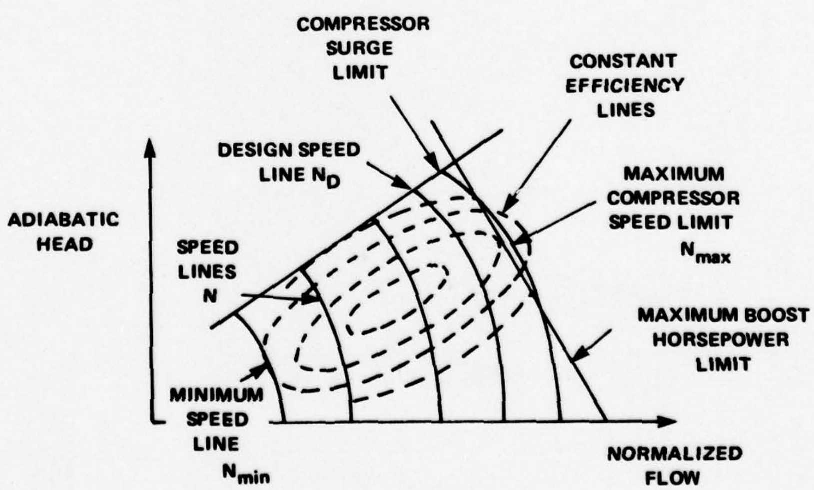
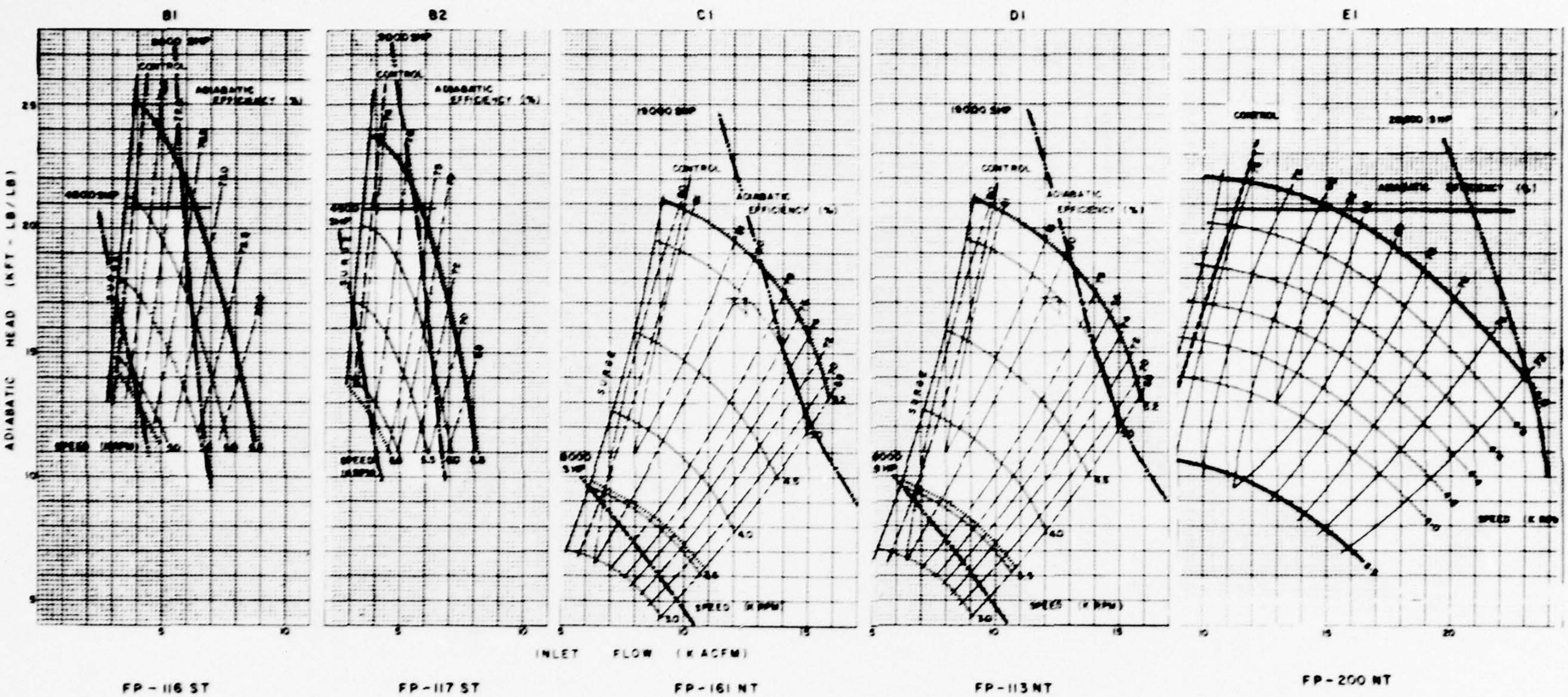


FIG. 8: CENTRIFUGAL COMPRESSOR MODEL DATA



NOTE: ALL UNITS IN PARALLEL OPERATION. HEAD IS LIMITED ON B1, B2 AND E1 DUE TO CHARACTERISTIC OF C1 AND D1

FIG. 9: COMPRESSOR DATA FOR STATION 2

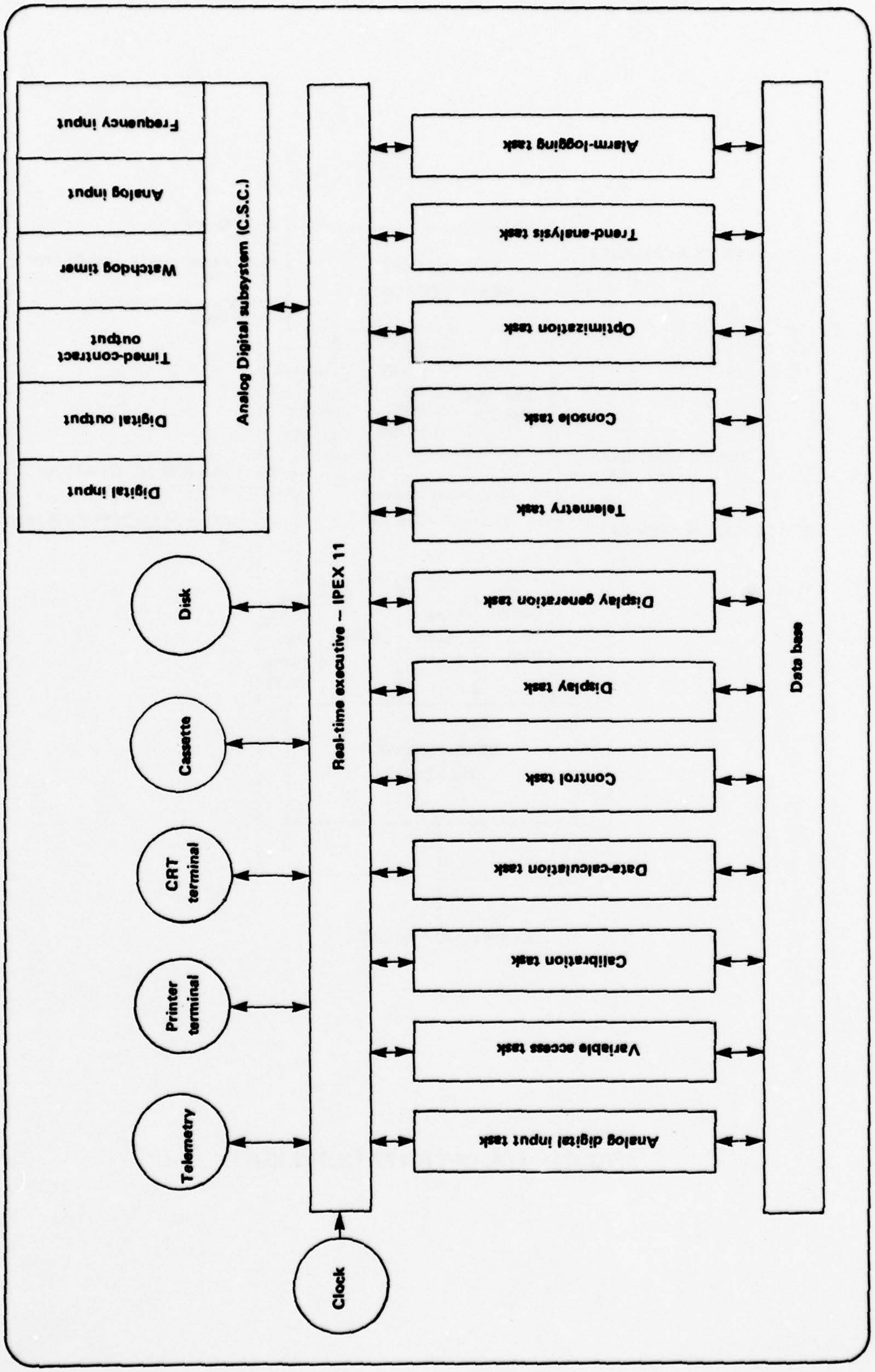


FIG. 10: COMPRESSOR–STATION–CONTROL SOFTWARE ORGANIZATION

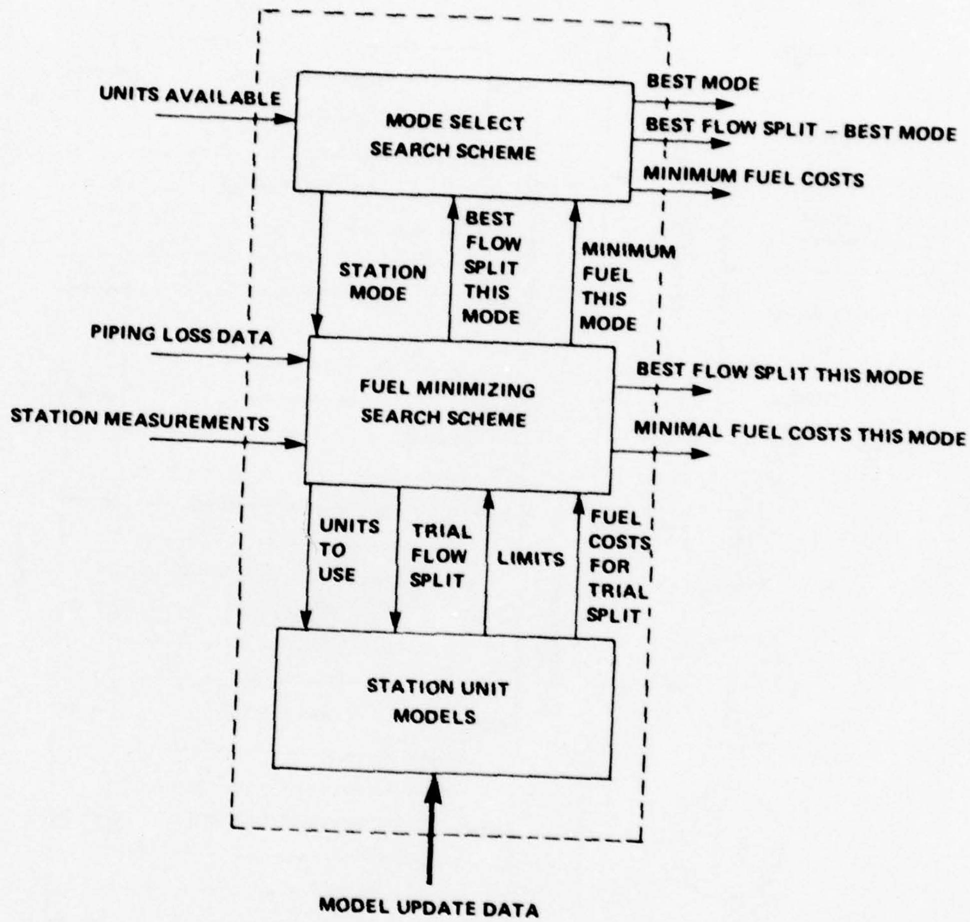


FIG. 11: THE OPTIMIZATION TASK

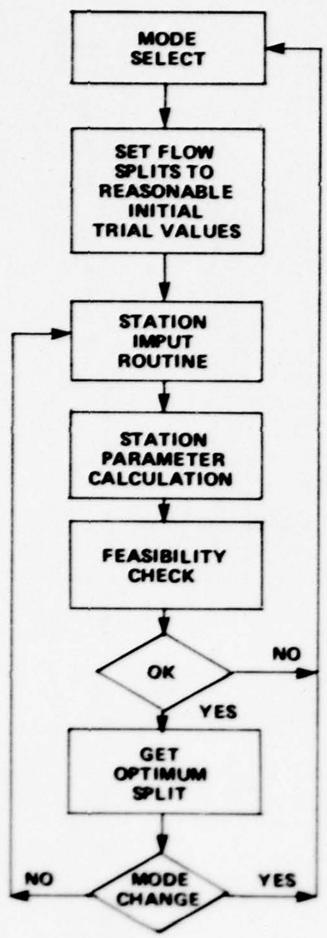


FIG. 12: OPTIMIZER FLOW CHART

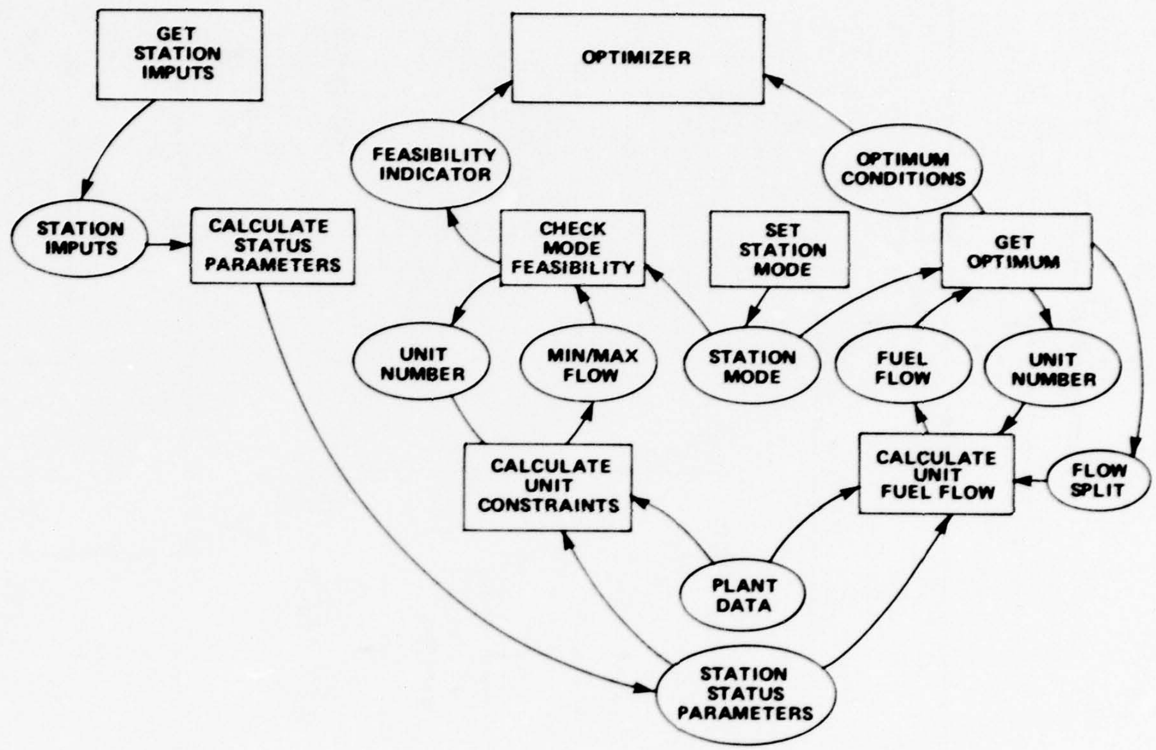


FIG. 13: OPTIMIZER DATA FLOW AND PROCESSING MODULES

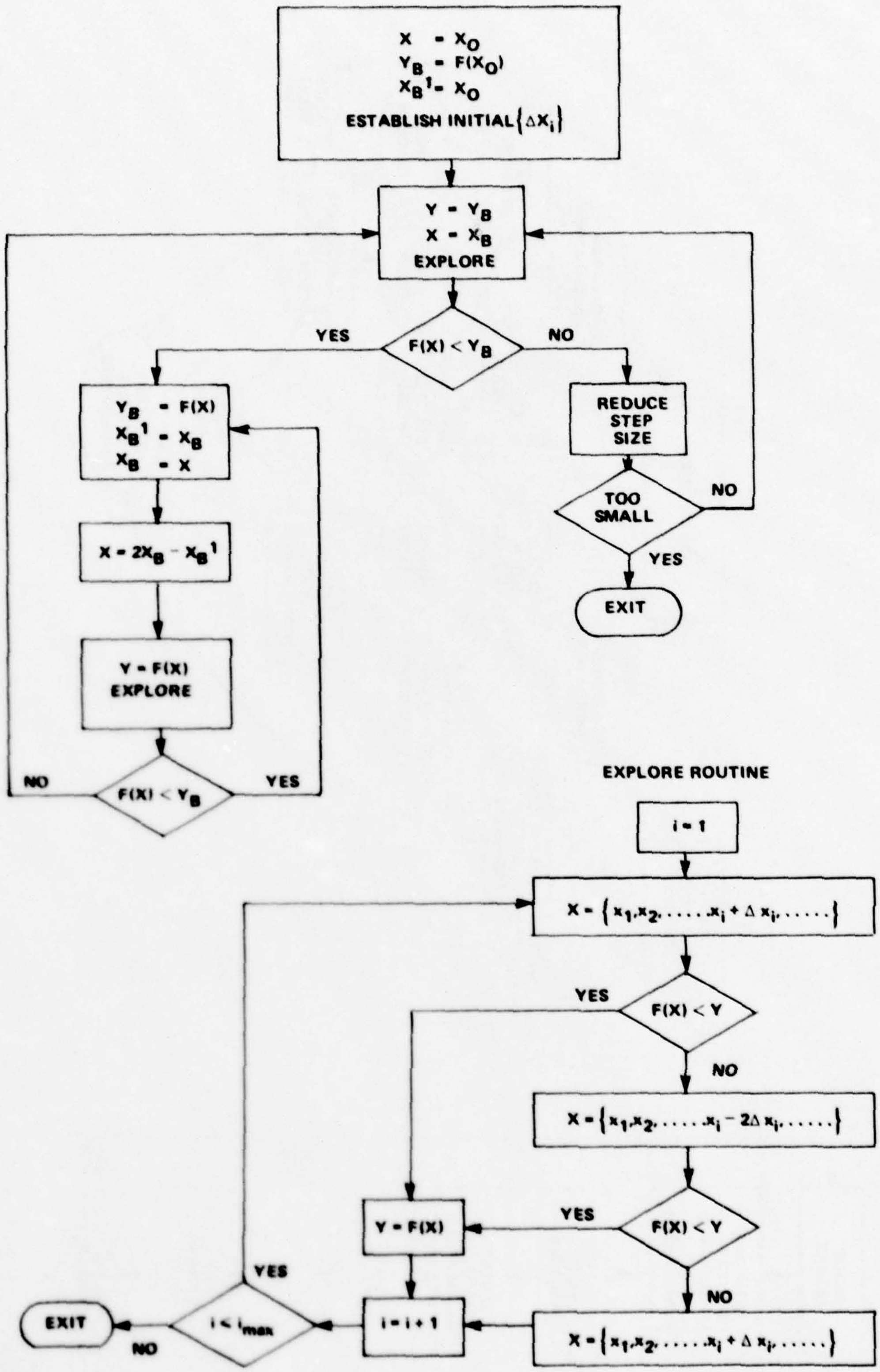
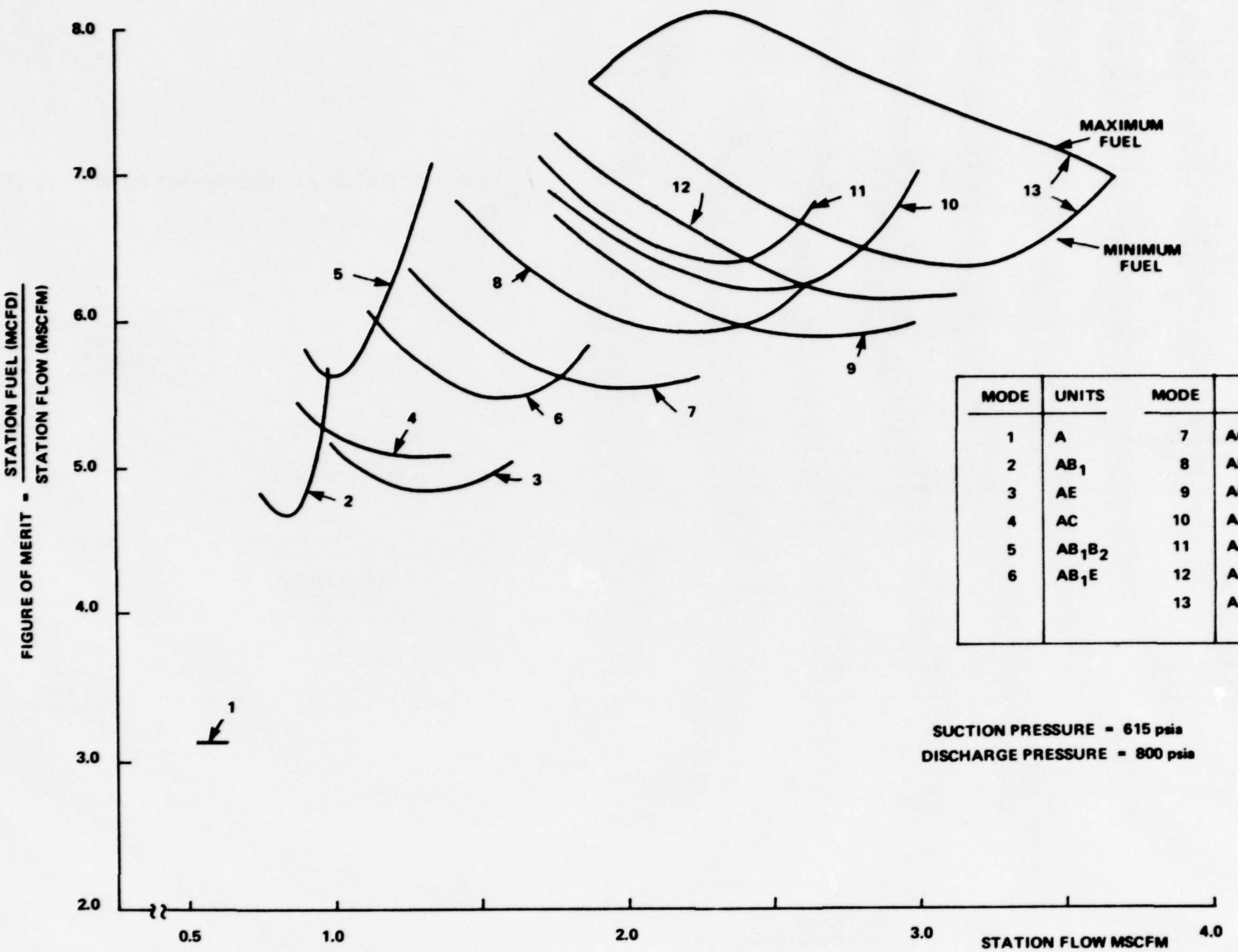


FIG. 14: PATTERN SEARCH ALGORITHM



MODE	UNITS	MODE	UNITS
1	A	7	ACE
2	AB_1	8	AB_1CE
3	AE	9	ACDE
4	AC	10	AB_1B_2DE
5	AB_1B_2	11	AB_1B_2CD
6	AB_1E	12	AB_2CDE
		13	AB_1B_2CDE

FIG. 15: COMPUTED OPTIMUM FUEL – STATION 2

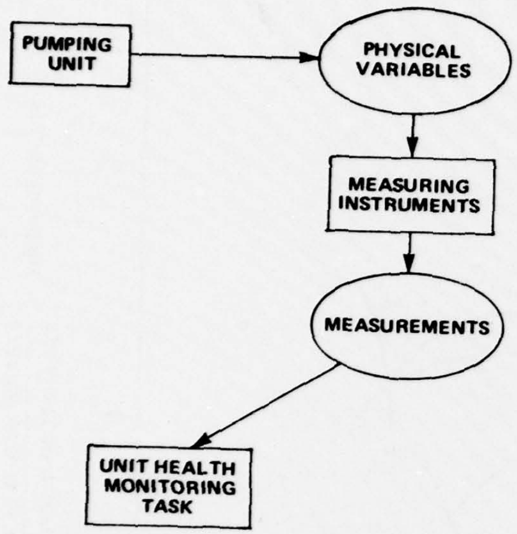


FIG. 16: UNIT MONITORING TASK OVERVIEW

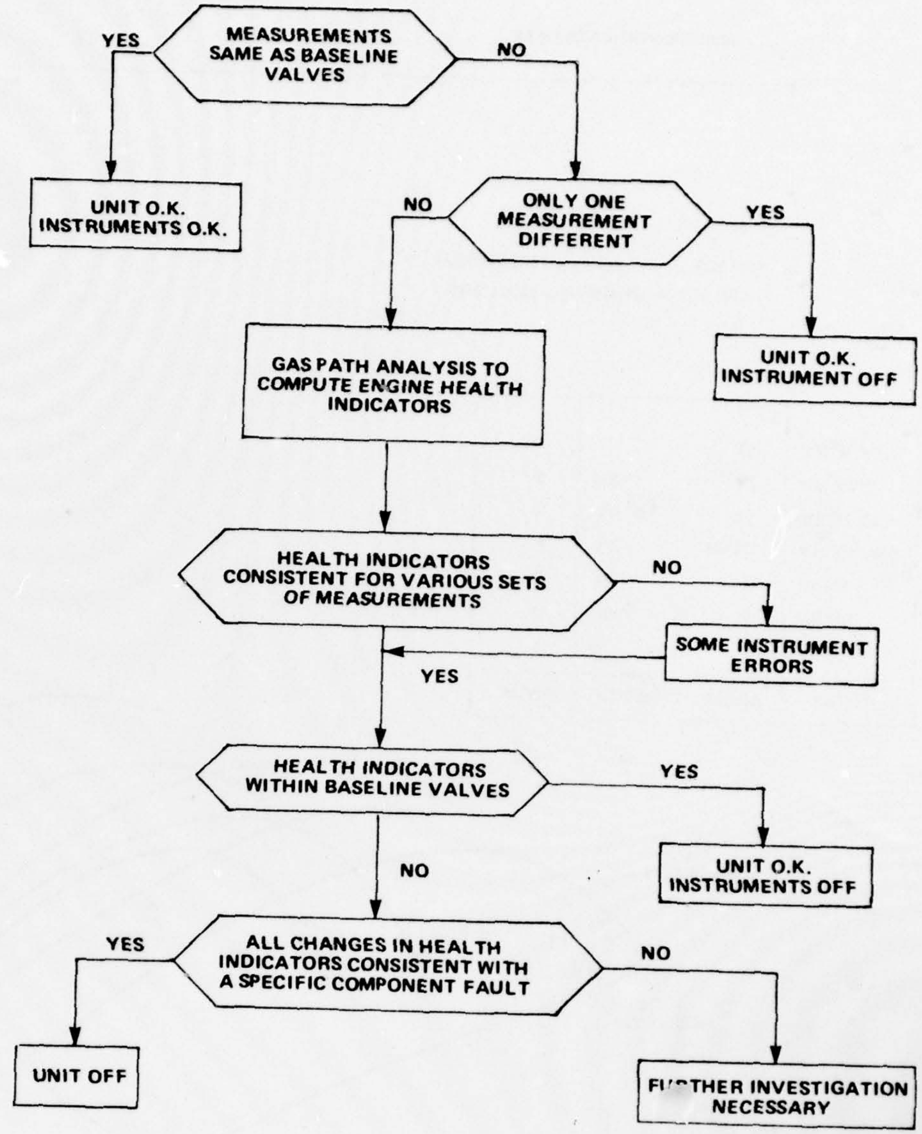


FIG. 17: MEASUREMENT VALIDATION TASK

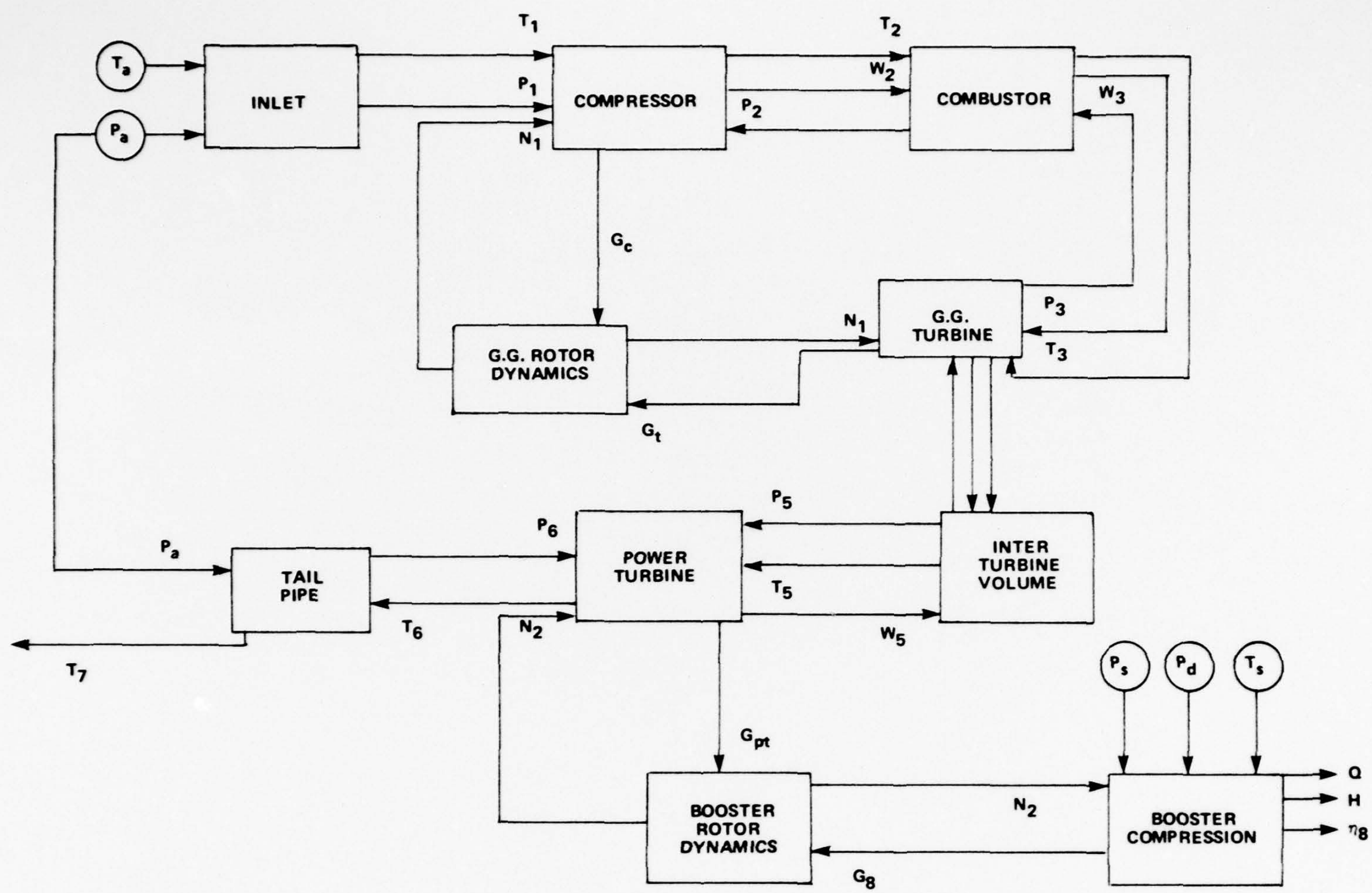


FIG. 18: INFORMATION FLOW DIAGRAM FOR COMPUTER MODEL

A RAILWAY TRACK SWITCH THAT OPERATES IN SNOW AND ICE

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Low Temperature Laboratory

Division of Mechanical Engineering

ABSTRACT

A new railway track switch has been designed to operate successfully in snow, ice and cold without assistance from auxiliary devices. Laboratory testing of a prototype showed that the required forces to throw the switch under these climatic conditions were within the capacity of a conventional electric switch machine. Field testing of the prototype, over a period of almost two years in track on a heavy duty, slow speed application at the CP Rail St. Luc Yard, showed that the switch could operate successfully under reasonably severe snow conditions with only minimal snow removal. It was not seriously tested by ice build-up from freezing rain. Although strain gauge measurements showed no structural problems with the switch, a number of design modifications have been recommended to improve the mechanical performance and endurance of the switch.

1.0 INTRODUCTION

1.1 The Split Switch

Throughout railway track work the split or point switch is used almost exclusively. In most respects it performs its function well at low cost and with little attention. However, when even a small amount of snow accumulates between the point rail and the stock rail, the switch will fail to fully close when thrown, as the snow compresses into a solid with considerable compressive strength. The original solution to this problem was simply to sweep the snow out from the critical areas with hand brooms. While this was satisfactory at one time, the delays and high costs of this method are no longer tolerable for many switches of a modern railway.

1.2 Thermal Protection of the Split Switch

Switch heating devices of many types are now in fairly widespread use. The most popular and most effective type currently in use in Canada blows heated air into the critical areas of a split switch to melt or vapourize the snow either as it falls or after it has accumulated. Such switch heaters operate in either a fully automatic mode using snow detectors or a remotely controlled mode by dispatcher choice. The design and performance of a prototype switch heater of this general type was reported in References 1 and 2.

Switch heaters, however, require a capital expenditure of the same order as that for the switch itself; as much as 6000 litres or more of fuel per year, depending on the particular system used and its location; and considerable maintenance to repair, adjust and refuel the system.

1.3 Non-Thermal Protection of the Split Switch

By placing a high velocity horizontal curtain of unheated air over the critical areas of a split switch, snow can be prevented from fouling the switch (Ref. 3). Such a horizontal air curtain device costs less than a switch heater both to install and to operate. However, it does require a considerable amount of often scarce electrical power (5 kw) to drive the fan. Also, it does not have the recovery capability that switch heaters have to clear a switch that has become fouled with snow for any of a number of reasons, e.g. due to a power failure during a snow storm.

1.4 Passive Switch Protection

Both thermal and non-thermal protection methods require active fuel and/or power consuming systems. Another potentially more attractive alternative is a passive system that protects merely by its presence. While the construction of snow sheds over the entire switch can provide some measure of protection, no reliable and economical way has yet been found to provide passive protection of a split switch. Consequently, the Division of Mechanical Engineering has investigated two alternative switch designs that would provide their own passive protection. One of these designs, the Horizontal Traverse Switch, developed by the Low Temperature Laboratory, will be described along with the results of laboratory and field evaluation of the first prototype switch (Refs. 4,5,6).

2.0 DESIGN OF THE SWITCH

2.1 Principles

In designing the Horizontal Traverse Switch the following principles governed.

2.1.1 No components may close on, or closely approach, other components such that snow or ice can be compressed between them. Any positioning stops, for example, must be fully protected from exposure to snow and ice.

2.1.2 The switch must not extend beyond the essential dimensional limits of existing switches. Special roadbed modifications must be avoided.

2.1.3 The switch must be structurally compatible with existing track and must adequately withstand all external loads normally applied to switches.

2.1.4 The switch must be compatible with present switch machines and signal systems.

2.1.5 The switch must not require auxiliary devices or special maintenance for successful performance in snow and ice.

2.1.6 Switch components, especially the main structural sections, must be amenable to low cost mass production techniques.

2.2 Description of the Switch

The Horizontal Traverse Switch (Fig. 1) is a unique stub switch utilizing pivoted, double-headed rails swinging in a horizontal plane so that one head aligns when set for straight-through and the second head aligns when set for turnout. A built-in device positions and locks each rail in either of the two positions. The rails are supported through thin, flat bearings by rail support sections that also enclose the pivot bearings and the positioning and locking devices. Each rail support is fastened down to a full length baseplate that extends beyond each end of the switch rails and under the stock rails. Four gauge plate beams tie the two rail support and baseplate assemblies together. A conventional switch machine operates the switch.

The prototype was designed to replace a 6.7 m split switch and to be compatible with 52 kg AREA rail.

2.3 Features of the Switch

2.3.1 The use of a double-headed rail allows the rail to be pivoted on a large bearing (Figs. 1 and 1(c)) protected from exposure to snow and ice while aligning accurately to the stock rails at each end. Such pivoted movement eliminates any compressive closure, substituting instead only shear between the switch rails and the stock rails at both heel and "point" ends.

2.3.2 The wide flanges of the double-headed rail shield the rail supporting bearing surfaces from snow and ice (Fig. 1(a)). They also provide lateral strength to support the loads encountered in changing a train's direction on turnout, minimize lateral deflections, and they resist any tendency of the rails to tip, under side loads.

2.3.3 The built-in stops positively align the switch rails to the stock rails, and the wedge locking bars, operated by the switch machine, keep the rails securely in this position (Figs. 1 and 1(b)). This entire mechanism is protected from exposure to snow and ice by its containment within the rail support section and the wide flanged cover provided by the double-headed rail.

2.3.4 As the rails are transferred from one position to the other, they slide on low friction, thin, flat bearings, some of TFE impregnated sintered bronze and some of reinforced TFE (Figs. 1 and 1(a)). A water resistant, low temperature EP grease is used to provide some lubrication to the bearings, but mainly to prevent ice, which might form between the rails and their supports, from bonding strongly to their surfaces. The bearings are spaced at approximately 50 cm centre to centre so that deflection of the rails cannot extrude the grease from between the rails and their supports.

2.3.5 The wide rail support section (Fig. 1(a)) provides wide-stance support of the rail, thus avoiding any tendency of the rail to tip over. This section also provides an enclosure protecting the critical positioning stops and pivot bearing from blowing snow, dirt, etc. (Figs. 1(b) and 1(c)).

2.3.6 The rail support section is securely bolted to the full length baseplate (Figs. 1 and 1(a)), which also extends under the stock rails at both ends to the second tie beyond the switch itself to provide a means of anchoring the ends of the stock rails in alignment with the switch rails.

2.3.7 As well as controlling the track gauge at critical locations, the two gauge plate beams at the ends of the switch (Fig. 1) are reinforced to strengthen the joints between the ends of the switch itself and the adjoining stock rails. Another gauge plate, located close to the stops, controls the positions of the switch rails at both ends of the throw.

2.3.8 The switch is driven by a conventional electric switch machine (Figs. 1 and 14). However, by orienting the switch machine with the motor toward the "point" end of the switch rather than the heel end, maximum leverage for throwing the switch can be obtained and a simple add-on device provides a drive for the switch locking mechanism directly from the protruding locking bar of the switch machine. The lock rods and point detector rods of the switch machine are operated together, as a unit, driven by rods connected to both rails.

To maintain adequate clearance between the switch rods and the baseplates under heavy icing conditions, all switch rods were lowered and suitable offsets were made in the throw, lock and point detector rods so that the switch machine would remain at the standard elevation relative to the rail. Where the bearing clips necessarily had to closely approach the baseplate, the faces were relieved to provide a wedge to part the snow rather than compress it (Fig. 1).

2.3.9 Strength of the composite section is greater than for the equivalent standard rail. The double-headed rail, itself, is made from type T1 structural steel quenched and tempered to 320 Brinnel hardness so that wear resistance would be maximized and cold worked distortions of the rail ends would be minimized.

2.3.10 The switch fits in essentially the same space as existing switches of the same size. No special modifications to the roadbed are necessary.

2.3.11 The switch can be set up in left, right or equal turnout positions interchangeably and with minor modifications the switch machine can be located on either side of the switch. As far as possible similar parts have been made interchangeable.

2.3.12 The double-headed rail and rail support sections have been designed so that they can be mass produced by rolling.

2.4 Stress Analysis

Because of the complex and largely unknown distribution of the support-mechanisms and because of the normal deviations of real equipment from theoretical models, it was realized that only measurements under actual loading conditions in a field installation could yield *reliable* stress information. However, through theoretical stress analysis, the locations where critical stresses may be encountered were identified.

In an attempt to predict, at least approximately, the operating stresses in the switch when a train passes over it, a set of strain gauges was installed on the prototype of the switch at locations where the theoretical stress analysis had shown the highest stresses could be expected. Then, as a 950-kg wheel set was rolled over the switch, causing small stresses in the switch components, the signals from the strain gauges were recorded on a multi-channel oscillograph recorder. From these recordings order of magnitude estimates were made of the maximum stresses that could be expected from a 36,000 kg/axle load. The maximum expected stresses, the nominal yield strengths of the steels, and the resulting factors of safety were as follows:

Component	Yield Strength (MPa)	Simple Bending Stress (MPa)	Factor of Safety
Double headed rail	965	200	4.8
Rail support	345	120	2.9
Baseplate	345	inconclusive data	

For the baseplate the loading was believed to be insufficient to bring all the support mechanisms into action. However, as a result of the measurements it was recommended that the first loading of the switch in the field be limited to about 9,000 kg/axle to ensure no overstressing of the baseplate. Otherwise the switch was expected to have sufficient structural strength for the service intended.

3.0 LABORATORY DEVELOPMENT OF THE SWITCH

Laboratory investigations centred around the switching characteristics of the Horizontal Traverse Switch under various environmental conditions. In all, more than one hundred tests were run at temperatures ranging from $-40^{\circ}C$ to over $+25^{\circ}C$, many with varying amounts of snow or ice on the switch.

3.1 Test Configurations

For the initial series of tests the switch was operated by a hydraulic system, and lubrication between the double-headed rails and their rail supports was provided by dry powdered molybdenum disulphide, applied directly to the steel sliding surfaces.

Since the first test series established that the throw force required to operate the switch was within the capabilities of conventional switch machines, the hydraulic system was replaced with a conventional electric switch machine for the second series of tests. Although the required throw forces found during the initial series of tests had been satisfactory, corrosion, with subsequent galling of the steel surfaces of the rail supports, became noticeable midway through the second series of tests. Thus, the dry powdered MoS_2 lubrication was abandoned.

So that other aspects of the switch development could continue while awaiting delivery of the materials required to modify the switch to that arrangement used for the third series of tests, a low temperature EP grease with good resistance to water was tried, again applied directly to the steel sliding surfaces. As expected, this series of tests showed that the throw force requirements were excessive with this method of lubrication.

To reduce friction and to eliminate steel to steel contact, the first eight individual flat bearings of TFE and lead impregnated sintered bronze, about 0.75 mm thick, were bonded to the top surfaces of the rail supports, such that the double-headed rails were supported through the bearings. The entire interface between the rails and their supports was filled with an all-weather, water resistant, calcium soap based, railway grease having MoS_2 and graphite EP additives. While incidentally providing lubrication to minimize friction, the grease was primarily meant to prevent corrosion and to prevent any water that might enter the interface from freezing to the rail and/or support surfaces with any degree of strength.

Since the third series of tests produced satisfactory results, the remaining eighteen bearings of reinforced TFE were bonded to the rail supports to provide proper support under train loads. A few tests were run to confirm that no adverse change in performance had resulted. This fourth configuration remained as the final one.

3.2 Test Equipment

For all but the final series of tests the switch was set up in the No. 1 Cold Chamber where the environment could be controlled.

For the first series of tests a hydraulic system was used to throw the switch. At maximum system pressure the hydraulic cylinder was capable of providing a throw force in excess of 33 kN.

For the second, third and fourth series of tests a conventional 32V DC electric switch machine was used to operate the switch. An adjustable voltage DC power supply powered the switch machine through conventional controllers.

A single copper-constantan thermocouple was placed in one of the locking bar guides of the switch to provide a measure of the "deep" rail temperature. The existing shielded thermocouple on the south wall of Chamber 1A was used to measure the chamber air temperature.

Four strain gauges, mounted in a temperature compensating full bridge configuration on a steel throw rod and calibrated from 26.7 kN compression to 26.7 kN tension, measured the force required to throw the switch.

3.3 Test Procedures

Test conditions were established in the cold chamber with the existing refrigeration system and freezing rain and snow-making equipment. During cool-down, the chamber temperature was depressed below the required rail temperature in order to accelerate cooling of the rail. When sufficient time was available before a test, the chamber temperature was brought into approximate equilibrium with the rail temperature.

Freezing rain was made at various temperatures between −18°C and 0°C. After sufficient ice had been built up by the freezing rain, it was hardened by depressing the chamber temperature to near −18°C for the first test series and to near −7°C for the second and third test series, before testing for the throw force. For test No. 127 only, exceptionally severe icing was created by applying water from a laboratory wash bottle directly to the switch "points" with the chamber and rail temperatures near −18°C.

Snow was made at temperatures ranging from −35°C to −15°C.

3.3.1 Measurements of Test Conditions

The "deep" rail temperature was taken as the test temperature.

Ice thickness was measured at the switch "points"; average snow depth resulted from measurements taken at twelve locations distributed throughout the switch; and snow depth at the switch "points" was averaged from those measurements closest to the switch "points".

Ice density was determined gravimetrically by displacement of ice water, while snow density was determined (approximately) by comparing the weight of snow in a carefully filled container to the weight of water that the same container would hold.

3.3.2 Test Measurements

For most of the throw force measurements a test consisted of ten consecutive throws of the switch with the first throw moving the rails towards the switch machine or hydraulic cylinder. When using the electric switch machine, the DC power supply was set to provide the nominal voltage at the switch machine terminals. For most of the tests involving a critical first throw, the "normal operating voltage" of 20 volts was used as specified in the A.A.R. Signal Section Specification 101-52, Part 104. Throw rod strain and, except for the first test series, actual switch machine voltage and current were continuously recorded during the tests.

For tests No. 317 and 350 one throw was made every 15 minutes during a continuous heavy snowfall, with the first throw occurring 15 minutes after the beginning of the snowfall.

3.4 Throw Force Requirements

It was found that the force required to throw the prototype Horizontal Traverse Switch ranged from less than 0.9 kN to more than 18 kN, depending mainly upon the test conditions, but, to some extent, also upon the particular configuration under test.

With each configuration, the required throw force varied considerably during a series of tests, often even when test conditions were apparently similar. While high forces were required when breaking ice, initially pushing snow aside, or compacting snow, the throw force with ice and/or snow on the switch otherwise was not appreciably greater than that required to throw the switch under nominally dry conditions at the same temperature. Furthermore, for much of the testing, the effects of variables other than temperature were not easily recognizable.

3.4.1 Effect of Dry Cold

Figure 2 shows a typical throw when the switch was dry and warm, while Figure 3 shows a typical throw in dry cold conditions. The initial peak in the throw force measurement is apparently due to the absorption of some of the inertia developed by the switch machine before actually starting to move the switch rails.

It was found that, during the final test of the first test series, a rapid increase of almost 0.9 kN throw force occurred in the course of one of the test throws. This increased force persisted throughout the remaining throws of this test. For dry MoS_2 lubrication, the throw force required during the second test series was also of the order of 0.9 kN higher than for the first series. Subsequent disassembly of the switch and inspection of the sliding surfaces confirmed that corrosion with subsequent galling of the rail supports was occurring. Because any degree of galling is totally unacceptable and because it would surely become more extensive and thus lead to greatly increased throw force requirements, the dry MoS_2 lubrication was abandoned.

As expected, the viscous friction of low temperature EP grease lubrication, directly between the steel surfaces over the large areas involved, resulted in throw force requirements even higher than in the galled condition described above. Especially when considering the effect that viscous friction would have at lower temperatures, the throw force requirements with this configuration were regarded as excessive.

With the installation of the individual flat impregnated bronze bearings to support the rail and the application of the all-weather grease, the required throw force was reduced to acceptable levels. Although the particular grease used during this test series remained quite plastic, even at the lowest temperatures, the throw force increased as the temperature decreased, due mostly to increased viscous friction of the grease.

Some significant increases in throw force requirements were found when the temperature was below freezing after the switch had been subjected to a number of very wet freeze-thaw cycles. These increased throw forces occurred whether or not snow and/or ice was on the switch. Since water was found between the rails and their supports on disassembly after this series of tests, and since this water would be ice when the rails were below freezing, it appears that such ice was the cause of these increased throw force requirements.

Exceptionally low throw forces were found in the Series 4 tests apparently resulting from the addition of the reinforced TFE bearings. Since the switch was ready for field installation, further tests with this configuration were postponed to avoid delay in shipment, so that the switch could be installed in track over the winter of 1974-75.

3.4.2 Effect of Freezing Rain

Figure 4 shows ice typical of that made from freezing rain, while Figure 5 shows a typical first throw breaking free of ice. The exceptionally severe icing created for test No. 127 and its effect on throw force can be seen in Figures 6 and 7. Such severe conditions are beyond those expected to be encountered in the natural environment. Both Figures 5 and 7 illustrate the characteristics typical of breaking free of ice, a high initial peak force that occurred very close to the start of the throw, followed by a sudden break, with the force dropping to, or near to, zero before rising again to a fairly uniform level for the remainder of the throw. The extent of the drop from the peak suggests a significant elastic springing of the rails prior to the break. This was confirmed by visual observation during test No. 127.

The throw force required to break free of ice resulting from freezing rain was therefore determined from the initial peak force encountered during the first throws of those tests for which pertinent details are given in Table I. The effect of ice thickness on throw force is illustrated in Figure 8. Considering the imprecise nature of the ice thickness measurements, the variability of ice thickness on the switch and the variations in other test conditions, the test results were fairly consistent.

3.4.3 Effect of Snow

Typical of the heavy snowfalls used in the testing is that shown in Figure 9, and typical of the throw force requirements for the first throw in heavy snowfalls is Figure 10. The characteristics of Figure 10 and their resemblance to those of "dry" throws (e.g. Fig. 3) suggest that nothing other than increased frictional resistance occurs due to the presence of the snow. Shear of the snow and the weight of the snow adding to the bearing loads could account for this increase. However, when crusty or icy snow was formed around the "points", the required throw force showed the characteristics of breaking weak ice, i.e. it required an initially higher force to break free than to continue movement.

Pertinent details of the first throw which initially displaced snow after each fresh snowfall are presented in Table II. The throw forces encountered in the first and third test series fell within essentially the same range. However, those of the second test series reflect the 1.3 to 1.8 kN higher "dry" throw force required with the low temperature EP grease lubrication. Varying severity of icing and/or crusting of the snow made on the "point" end of the switch during many of the tests undoubtedly contributed to the lack of significant relationships found in this data.

In Figure 11 the only occurrence, during all the testing, of significant snow compression at the end of the throw can be seen to have resulted in failure to close the switch. The cause of this snow compression was found to be the closure of the original flat inner faces of the bearing clips to within about 6 mm of the edges of the baseplate and rail support. This problem was eliminated before proceeding with further testing by chamfering the inner edges of the bearing clips to form a "knife edge" as illustrated in Figure 1.

Also apparent in Figure 11 is a "stick-slip" cycling while moving the heavy snow load through the main portion of the throw. This is believed to be associated with displacement of the snow by a mechanism of snow compaction, followed by shear displacing the compacted snow upward out of the way of the compacting edge of the switch rail. This cycle then continued to repeat with fresh snow being compacted in each cycle until the end of the throw was reached (whether or not the switch was fully closed).

For the two tests Nos. 317 and 350 the repeated throwing of the switch during continuous heavy snowfalls resulted in accumulations of displaced and subsequently compacted snow as illustrated by Figure 12. During the final 10 to 15% of the last throw of test No. 317 (see Fig. 13) the switch machine almost stalled three times before finally completing the throw.

4.0 FIELD INSTALLATION OF PROTOTYPE

After weathering for almost a year in the CP Rail St. Luc Yard, and prior to installation in track, the Horizontal Traverse Switch was inspected to ensure that it was in proper condition. It was found that a number of the flat bearings supporting the rails had become unbonded. All bearings were subsequently checked and those that showed any sign of poor bonding were replaced. As expected, the strain gauges installed for stress testing were found to be unserviceable. A complete new set was installed. At this same time two additional strain gauges were installed.

In early November 1975 the Horizontal Traverse Switch was placed in track on the lead into the St. Luc Diesel Shop (Fig. 14). It replaced a manually thrown 5 m split switch built of 45 kg rail. Almost all traffic over this switch consisted of diesel locomotives entering the shop for servicing. Drainage of surface water was described as rather poor at this site.

After removal of the split switch and about one length of the stock rails at either end, the site was excavated to a depth of about 0.6 m. The Horizontal Traverse Switch was then placed in position somewhat further from the frog than the split switch because of its smaller turnout angle. New 52 kg rails were cut to the required lengths, with the appropriate angles on those at the heel of the switch. They were drilled, where necessary, for connection to the switch and to the adjacent lengths of stock rail. These new rails were first bolted to the baseplates of the switch through special rail anchors and then to the adjacent 45 kg stock rails through compromise joints. The entire track was visually aligned and leveled with the turnout stock rails simply being curved to blend smoothly at each end. Crushed rock ballast was placed and tamped around the switch as final level adjustments were made. Rail anchors were added to each length of stock rail immediately adjacent to the switch.

The switch machine was installed and powered by two 12-volt batteries placed in series. Battery charge was maintained with standard railway trickle chargers from a 110-volt AC line that had been brought close to the switch. To indicate alignment of the switch an elevated pot signal was installed near it and on the post of the pot signal, a toggle switch was provided to operate the switch machine.

To monitor the use of the Horizontal Traverse Switch, an axle counter was installed on one of the stock rails near the "point" end of the switch, and throw counters had previously been installed in the switch machine.

The first pass over the Horizontal Traverse Switch occurred at about 1600 hours on 5 November 1975 as soon as the straight through track was negotiable. However, since the roadbed was still soft, especially under temporary headblocks, considerable deflections occurred, the only notable one being about 5 cm at the "point" end of the left switch rail. The roadbed was firmed up considerably before any further traffic passed over the switch.

Installation of the Horizontal Traverse Switch was completed on 7 November 1975 and it was officially placed in service at 1500 hours on 10 November 1975.

4.1 Installation Problems

4.1.1 Cutting Stock Rails

The need to cut the stock rails at an angle to fit the heel of the switch required a special set-up on a saw in the shop. It could not be done in the field.

4.1.2 Drilling Stock Rails

The non-standard drilling of the special rail anchors required extra cutting and drilling of the stock rails in the field.

4.1.3 Aligning Rail Ends

Considerable difficulty was experienced in aligning some of the holes when bolting the special rail anchors to the baseplate, while at the same time attempting to align the stock rail ends to the switch rail ends.

4.1.4 Switch Rail Clearances

No provisions had been made for positively controlling the proper clearances between the switch and stock rails. The stock rails simply were positioned to provide the necessary gap and the rail anchors at each tie relied on to maintain the gap.

4.1.5 Roadbed

Support of the switch was apparently non-uniform, especially under the left switch rail. The "point" end of this rail, even when unloaded, did not rest on its bearings. Apparently, it was "cantilevered" from another bearing some distance from the "point" end. After a number of attempts to correct this condition by lifting the rail and adding ballast, some improvement was realized, but it remained clear of the "point" end bearing by about 3 mm. As each locomotive wheel set approached the switch from the "point" end, deflection of the stock rail and base of the switch increased this clearance to between 9 mm and 13 mm. Consequently, this switch rail was hammered severely by the passage of each wheel set in this direction. On a reverse pass it would simply spring back as the load was released. There was some deflection under the heel end of this rail such that its "point" end was lifted slightly by a wheel on the extreme heel end.

The more solid conditions under the "point" end of the right switch rail resulted in a hammering of only about 3 mm in total. No noticeable deflections couid be seen at the heel end of this rail.

Spacers subsequently welded to the top of the switch rods to hold down the switch rails reduced, but did not eliminate, the hammering of the "point" end of the rails.

4.1.6 Axle Counter

It was noted that the axle counter was picking up spurious signals. After measures had been taken to de-couple the counter from each suspected source, the sensitivity of the counter was reduced. Although wheels passing the counter transducer at crawl speed could not be counted, extraneous counts apparently ceased.

4.2 Design Modifications

Redesign of the two ends of the Horizontal Traverse Switch to include stock rail sections as part of the switch could eliminate most of the installation problems. Alignment and clearances relative to the switch rail ends could be provided.

Additional strength and stiffness through to the ends of the stock rails could minimize deflections resulting from poor roadbed support. A method of holding down the "point" end of the switch rails could eliminate the hammering of these rails. Standard rail joint bars could be used for connection to adjacent stock rails, thus eliminating much of the cutting and drilling in the field as well as any special cuts.

5.0 SWITCH STRESSES

To determine the stress levels in the Horizontal Traverse Switch under service conditions, a series of strain gauge measurements was conducted on 25 November 1975 with the assistance of the Railway Laboratory (see Appendix for details).

5.1 Factors of Safety

Comparing below, the maximum stresses determined from the strain gauge measurements to the nominal yield strengths of the steels used for each of the sections reveals that adequate factors of safety were realized during the testing.

Component	Yield Strength (MPa)	Simple Bending Stress (MPa)	Factor of Safety
Double headed rail	965	105	9.2
Rail support	345	90	3.8
Baseplate	345	70	4.9

With the principal stress of 105 MPa in the left inside rail head at the locking device the factor of safety was 9.2 also.

Extrapolating to the design load of 36,000 kg/axle results in the following stresses and factors of safety.

Component	Yield Strength (MPa)	Simple Bending Stress (MPa)	Factor of Safety
Double headed rail	965	145	6.7
Rail support	345	125	2.8
Base plate	345	95	3.6

A further extrapolation of the stresses induced by the lateral thrust, due to a 48 km/h speed through the switch on turnout, raises the principal stress in the left inside rail head at the locking device to 160 MPa. A still acceptable factor of safety greater than 6.0 is obtained. However, calculations indicate that with these conditions, lateral deflection of the end of the rail would exceed 5 mm compared to slightly more than 1.5 mm for the worst test condition. Therefore, for high speed turnout service lateral support of the extreme "point" end of the switch rails will be required.

While the factor of safety of 2.8 for the rail support may appear somewhat low for live loading conditions, this is based on the rather conservative assumption that the rail support and base-plate bend as two independent bodies. If the opposite assumption is taken, i.e. that they bend as one solid body, the maximum stress in the rail support would be less than 60% of that reported and the factor of safety would be more than 4.5. Although the extent of the coupling of the two sections is unknown, the actual factor of safety should be adequate.

6.0 OPERATIONS

6.1 Service

The measurements of service provided by the axle counter are of doubtful reliability due to suspected spurious counts and due to the counter's insensitivity to traffic moving more slowly than about 5 km/h. However, when all factors are considered, it is estimated that in the order of 3 Mt of traffic passed over the switch in the one and three-quarter years that it was in track.

Although there were individual failures of the throw counters in the switch machine, there was collective evidence of at least 14,000 single switching operations over the entire trial, or about 22 throws per day.

6.2 Snow and Ice Conditions

Details of the snow and freezing rain that fell at nearby Dorval Airport during the two winters encompassed by the field trial are shown in Table III.

6.3 Operating Problems

In the first three weeks of service diesel locomotives were run through the open switch from the turnout track twice, once on 16 November 1975 and once on 25 November 1975.

Since the Horizontal Traverse Switch is a stub switch, any attempt to run through on the open rail head will result in a derailment. However, it is significant to note that after the first three weeks of service no further derailments were reported and no significant damage to the switch occurred as a result of the two derailments that did occur. In addition, no damage to the locomotives was reported.

7.0 PROTOTYPE PERFORMANCE IN SNOW AND ICE

7.1 Operation in Snow and Ice

The total snowfall was considerably above normal during the first winter and somewhat below normal during the second. However, each winter had two fairly severe storms with one daily snowfall near 25 cm and one other above 20 cm.

It had been requested at the beginning of the trial that the Horizontal Traverse Switch not receive the special attention to cleaning normally accorded to ordinary split switches, but only that normally accorded to track alone (Fig. 15). Actually, because of the flanges on the switch rails, plow blades had to be lifted as they crossed the switch. Therefore, more snow remained on the switch than on the adjacent track.

Figure 16 shows the "point" end of the right rail after throwing the switch in undisturbed snow and after return to the original position.

Twice during the first winter packed snow had to be removed from the adjustment bracket on the throw rod. Three other service calls for switch rods out-of-adjustment may have been attributable to the same fault.

During the second winter in service the only maintenance call involving snow was for "switch rods full of snow". Otherwise, it was reported that snow posed no problem for the switch; it continued to function properly even when completely buried by snow.

At no time during the two winters was the Horizontal Traverse Switch seriously challenged by freezing rain. On only four days did the freezing rain amount to about 5 mm or more, with a maximum of slightly less than 7 mm. However, the laboratory testing indicated that the switch should still be operable after more than 10 mm of ice has accumulated on it.

7.2 Design Modification

Other than the minor problem with snow packed in the adjustment brackets of the switch rods, no failures were attributed to snow even though the switch was at times completely buried by snow. A simple seal to exclude snow from the adjustment brackets should make the Horizontal Traverse Switch completely immune to reasonable amounts of snow.

8.0 PROTOTYPE MECHANICAL PERFORMANCE

8.1 Basic Structure

The basic structural components of the Horizontal Traverse Switch have shown no signs of structural deterioration, either during or after completion of the field trial. Even the excessive deflections that occurred during installation on the first pass over the switch apparently had no adverse effect.

8.2 Rail Support Bearings

Of the twenty-six flat bearings bonded to the rail support sections before the field trial, only three remained approximately in place at the end of the trial. The other twenty-three bearings had been periodically ejected from between the rails and their support sections, apparently after the bonding of the bearings to the rail supports failed. Although the bearings were somewhat distorted during ejection from the joints, only the reinforced TFE bearings showed signs of distortion from normal service. Except where the rails were not in actual contact with the rail supports, no grease remained between them and some minor corrosion had started, more so on the rail support than on the rail itself. From measurements of worn and unworn bearing thickness no significant wear was discernible from normal switch operation on either the TFE and lead impregnated sintered bronze or reinforced TFE flat bearings.

In May 1977, because of the apparently rapid and accelerating loss of the flat bearings from between the switch rails and the rail support sections, with the concomitant increase in the force required to throw the switch and, therefore, overloading of the switch machine, it was recommended that the switch be removed from track "as soon as a replacement switch can be made available". It was subsequently removed from track on 11 August 1977.

8.3 Alignment

By spring, after the first winter of service in track, the entire switch had rotated noticeably clockwise, due apparently to the lateral thrust from turnout traffic (Fig. 17). After the second winter the rotation was found to be much worse. It was also reported that while the switch had recently been realigned, it readily returned to the severe misaligned condition. However, it was noted at the same time that to drain the switch rod tie cribs and the switch machine site, a drainage ditch had been dug immediately adjacent to the ends of the ties and to the left of the switch. This ditch left the tie ends essentially without lateral support from the ballast for at least one-half the length of the switch.

Both "point" end stock rails became severely curved as their ends were deflected laterally with the "point" end of the switch (Fig. 18). However, while the stock rail anchors bent the left rail into an ogee shape, thus maintaining good alignment to the switch rail, a bolt missing from the right rail's anchors allowed this rail to avoid the reverse curvature and thus become misaligned with the switch rail. The direction of the curvature also resulted in the wheel flanges striking the tip of this stock rail and causing it to wear excessively. Otherwise, alignment of individual rail heads was satisfactory.

8.4 Cold Flow and Wear of Rail Heads

On six occasions during the trial, "tight rails", due either to longitudinal rail movements or cold flow of the ends of the rail heads, made it necessary to either "bump" or grind the rails to ease transfer of the switch. However, cold flow of the rail ends had apparently slowed, at least, after the first few months of service. By the end of the trial, cold flow had rounded off the ends of the rail heads so that the top surface of the rails at about 6 mm from the ends averaged .25 mm below the main rail surface.

After the first winter of service the straight-through head of the left switch rail had cold flowed along a considerable portion of its length. Only a very slight amount of cold flow had started on the right rail straight-through head. The turnout heads of both rails were entirely free of this defect. Inspection after completion of the trial showed that cold flow along the length of the rail heads had continued so that all but the left turnout rail head had measurable burring (Table IV). Possibly the side thrust from the wheel flanges served to minimize the cold flow of this particular head.

Since, for each rail head, the outside portion of the top surface remained unworn, the surface wear was measured by comparing the worn rail profile to the theoretical profile. The results are also shown in Table IV. Wear (and/or material displacement by cold flow) of the rail head surfaces was generally low, with only the left straight-through head showing more than minimal "wear".

Twelve measurements were made in the field after 18 months service of the hardness of the switch rail heads and two of the "point" end stock rail heads. Rockwell "A" scale readings were taken with a portable hardness tester directly on the rail heads with no preparation other than the wiping off of any dirt. The tester calibration was checked on a test specimen of known hardness immediately prior to the rail head testing and again on the following day.

While the calibration showed the instrument to be reading four units high on the Rockwell "C" scale, the error was stable. No attempt was made to correct the calibration in the field; therefore, the measurements of rail hardness were adjusted by subtracting two units from the Rockwell "A" scale readings (two units Rockwell "A" $\approx$ four units Rockwell "C"). Table V lists the adjusted measurements.

Because of the considerable variations in the hardness tests taken in the field and because of the calibration error of the instrument during those tests, careful measurements of surface hardness were made in the Laboratory with the instrument properly calibrated. The average hardness at each location with the equivalent Brinnell hardness and the overall average hardness is shown also in Table V.

The surface hardness of the rail heads as measured carefully in the Laboratory showed little variation (with no relationship to the cold flow) but considerable work hardening from the original rail hardness of 320 Brinnell. It is more likely that the cold flow is governed by core hardness rather than surface hardness.

8.5 Internal Components

After less than three months service internal roll-pins of the built-in locking mechanism sheared. However, for yard service, where speeds were low, it was expected that the switch machine lock was fully capable of resisting any small side thrusts that might try to move the switch rails away from the built-in stop. Thus, the built-in lock was considered redundant and therefore, it was left out of service. No problems resulting from this move occurred.

After completion of the field trial, examination of the internal locking mechanisms, pivots and pivot bearings did not reveal any new problems. Both wedge locking bars were still workable and in good condition despite being out-of-service for more than a year and one-half (Fig. 19(a)). The pivots and pivot bearings showed no signs of deterioration or wear (Fig. 19(b)). Some soft rust was found on the baseplates inside the rail support section cavities (Fig. 19(c)).

8.6 Switch Machine

Throughout the first winter there were a total of 11 service calls for switch machine problems, mostly due to water and ice in the various compartments. This was attributed to the relatively poor drainage, particularly at the switch machine. However, this problem was solved before the second winter by the provision of the drainage ditch which resulted in the severe misalignment from rotation of the switch.

Early in the second winter, a section broke out of the cast gear frame in the dual-control mechanism of the switch machine. The fracture occurred through the upper bearing of the hand-throw idler gear, apparently during an attempt to hand-throw the switch. Throughout the remainder of the winter the switch was thrown using only the power-throw option of the switch machine. Late in April 1977 the casting was welded in an attempt to return the hand-throw mechanism to service. However, the weld did not hold and the hand-throw remained out-of-service to the end of the trial.

Prior to the removal of the switch from track, the switch machine was labouring excessively, twice stalling in mid-throw. Although the throw could be completed with the hand-crank, the switch was removed from service after the second stall. It was removed from track in the next couple of days.

8.7 Design Modifications

While the flat bearings supporting the switch rails have not worn significantly, their bonding to the rail supports is obviously unsatisfactory. Superior bonding techniques may be available; however replacement with mechanically fastened bearings would increase bearing life and facilitate replacement when necessary. Since the reinforced TFE bearings were apparently distorted by normal service, best performance should be obtainable from bearings of, or at least surfaced with, the TFE and lead impregnated sintered bronze material. The spacing between the rail and support surfaces should not be changed significantly. This spacing is necessary to maintain the grease film and exclude dirt, snow and ice from the gap.

Rotation of the entire switch due to turnout forces was obviously accelerated when the digging of the drainage ditch removed the lateral support proved by the ballast. As the "point" end of the switch became significantly displaced, straight-through traffic could also provide forces causing rotation and even further displacement. The provision of extended sections of stock rail as part of the switch should provide additional resistance to rotation as long as normal ballasting is maintained. Where necessary, lateral anchors into the roadbed could be provided.

As well as simplifying installation and providing additional resistance to rotation, extended sections of stock rail, forming part of the switch itself, could permit accurate alignment and clearances to be maintained with a minimum of grinding of the rail ends. However, with a stub switch this need for grinding cannot be entirely eliminated.

For yard service the built-in locking mechanism should be left out of service. A modified design specifically to facilitate maintenance will still be necessary for high speed turnout duty.

Any corrosion found was of a minor nature. The bearing improvements discussed above will ensure that grease will remain on the mating surfaces of the rails and their supports with only occasional renewal. Further corrosion of these surfaces would then be eliminated. Application of a film of grease to the internal surfaces of the baseplate-rail support assemblies prior to assembly would retard the internal corrosion such as that found on the baseplates.

9.0 CONCLUSIONS AND RECOMMENDATIONS

A new railway track switch has been designed and a prototype has been tested in railway service. It is capable of operation in snow and in ice without special attention to snow clearing and without assistance from add-on snow protection devices.

9.1 Service

Over the one and three-quarter year period that the prototype Horizontal Traverse Switch was in track it provided generally satisfactory service under heavy duty slow speed conditions with minimal snow removal and minimal maintenance. Traffic over the switch amounted to about 3 Mt (mostly locomotives), requiring about 14,000 individual switching operations.

9.2 Performance in Snow and Ice

With snowfall ranging from below to above normal and including a few reasonably severe storms, the Horizontal Traverse Switch functioned properly during the two winters in track with only one minor problem attributed to snow. A seal to exclude snow from the adjustment brackets of the switch rods should be designed.

At no time during the field trial was the switch seriously tested by ice build-up from freezing rain. However, no problems were encountered with up to about 7 mm of freezing rain.

9.3 Mechanical Performance

From the strain gauge measurements, no overstressing of the major structural components of the switch was found. In addition, over the one and three-quarter year period of the field trial, no dangerous structural failures of the Horizontal Traverse Switch occurred and none appeared imminent. However, structural improvements can be made in joining the switch to the track at both ends of the switch. At the same time a number of functional failures and problems need to be remedied before the switch is again placed in track for further evaluation.

1) Low friction bearings, about 0.75 mm thick, capable of being operated dry, were found to be necessary between the rails and their supports. Then, by filling the spaces between the bearings with a water resistant grease having a low apparent viscosity at low temperatures, while still remaining in place at high temperatures, very little water can penetrate between the rails and their supports. In addition, the small but significant separation of the large surfaces of the rails and their supports greatly reduced friction due to viscous shear in the grease at low temperature. However, because of the bonding problem, the bearings should be redesigned to fasten mechanically to the rail support sections, but without significantly changing the spacing between the switch rails and their support sections.

2) Both ends of the switch should be redesigned to provide:

   a) continuous rail support sections to the ends of the baseplates,

   b) special stock rail sections that bolt to the extended rail supports and that extend beyond the ends sufficiently to provide additional resistance to rotation of the switch and connection to adjacent rails with standard rail joint bars, and

   c) proper alignment, clearances, hold-down and lateral support of the point end of the switch rails.

3) To maintain switch alignment, provision should be made to anchor the switch against lateral displacements from turnout forces. Perhaps pieces of old rail spiked to the bottom of the ties in a direction roughly parallel to the track could provide sufficient anchorage.

4) For the existing prototype switch the cold flow and surface hardness of the rail heads should be monitored during any subsequent in-track trials. For any replacement rails and/or new switches, the core hardness of the rail heads should be increased.

5) The design of the pivots and pivot bearings is satisfactory.

6) For slow speed yard service the built-in locking mechanism can be dispensed with. The switch machine locking system can be used to lock up the switch. However, in the event that the Horizontal Traverse Switch is placed in high speed service at some future date, a new drop-in unit design of locking mechanism with simple assembly and disassembly features should be provided.

7) The internal surfaces of the baseplates and rail supports should be thoroughly greased with a preservative grease before assembly to provide protection from corrosion.

9.4 General

Because it is a stub switch any attempted run-through will result in a derailment and grinding or other adjustment of the rail ends will be necessary periodically.

9.5 Future of Horizontal Traverse Switch

Subject to continued railway interest, the existing prototype of the Horizontal Traverse Switch should be modified as recommended above and reinstalled in track for further evaluation, preferably at a location in a yard where it will be subjected to much more frequent use.

10.0 ACKNOWLEDGEMENTS

The author wishes to thank Dr. R.F. Scott of the National Aeronautical Establishment — Structures Laboratory — for reviewing the theoretical stress analysis, Mr. W.J. Watson of the Railway Laboratory for the strain gauge installation, calibration and operation, and Mr. E.H. Taylor and all other involved personnel of CP Rail for their co-operation and assistance in conducting the field trial on this prototype switch.

11.0 REFERENCES

1. Coveney, D.B., Lane, J.F. *The 'Cyclone Switch Heater' for Railway Track Switches.* NRC/DME Lab. Tech. Report LTR-LT-65, National Research Council of Canada, Ottawa, June 1976.

2. Coveney, D.B. *The 'Cyclone Switch Heater' for Railway Track Switches — Part II. Prototype Performance Evaluation.* NRC/DME Lab. Tech. Report LTR-LT-93, National Research Council of Canada, Ottawa, January 1979.

3. Ringer, T.R. *An Energy-Conserving Railway Switch Protector.* NRC/DME Newsletter Vol. 1, No. 2, National Research Council of Canada, Ottawa, June 1975.

4. Coveney, D.B. *Railway Track Switch Operable in Snow and Ice — Part I. Design and Laboratory Evaluation.* NRC/DME Lab. Tech. Report LTR-LT-55, National Research Council of Canada, Ottawa, April 1975.

5. Coveney, D.B. *Railway Track Switch Operable in Snow and Ice — Part II. Prototype Field Installation, Testing and Performance.* NRC/DME Lab. Tech. Report LTR-LT-66, National Research Council of Canada, Ottawa, June 1976.

6. Coveney, D.B. *Railway Track Switch Operable in Snow and Ice — Part III. Prototype Performance Evaluation.* NRC/DME Lab. Tech. Report LTR-LT-87, National Research Council of Canada, Ottawa, April 1978.

TABLE I

FIRST THROWS IN FRESH ICE

		ICE		THROW FORCE
Test No.	Rail Temp. (°C)	Clear Thickness (mm)	Average Density (g/cm^3)	Initial Peak (kN)
Test Series #1 with dry MoS_2 lubrication				
109	-16	13	--	11.4
124	-7	13	--	15.9
126	-17	6	0.88	8.5
127	-18	16*	0.91	19.4
Test Series #3 with flat TFE and lead impregnated bronze bearings				
321	-3	6	0.92	8.3
325	-3	6	0.90	6.8
333	-4	9.5	0.90	10.1
337	-1	11	0.90	10.4

* Ice made on points only.

TABLE II

FIRST THROWS IN FRESH SNOW

Test No.	Rail Temp. (°C)	SNOW Avg. Depth (cm)	SNOW Avg. Density (g/cm³)	THROW FORCE Initial Peak (kN)	THROW FORCE High Force During Throw (kN)	THROW FORCE Compression Peak (kN)
Test Series #1 with dry MoS_2 lubrication						
117	-16	9.4	0.16	3.6	3.5	--
119	-21	16.5	0.17	4.2	6.3	34.7*
121	-27	8.9	0.13	5.4	3.2	--
Test Series #2 with low temperature EP grease lubrication						
232	-20	4.1	0.14	4.3	4.5	--
233	-17	16.5	0.29	6.0	7.4	--
Test Series #3 with flat TFE impregnated bronze bearings						
297	-18	12.4	0.31	5.2	6.1	--
301	-17	14.5	0.31	4.8	4.8	--
306	-16	15.5	0.22	4.1	3.1	--
310	-14	21.8	0.28	5.1	5.6	--

* Switch not closed. Force limited only by hydraulic system pressure relief setting. Modifications to "Bearing Clips" before further testing prevented recurrence.

TABLE III

SNOW AND ICE CONDITIONS
(data recorded at Dorval Airport)

Winter	1975/76	1976/77
Period covered: start	7 Nov.	17 Oct.
end	11 Apr.	8 Apr.
Total No. of Calendar days	156	174
No. of days with measurable snow	62	80
Total snowfall	301 cm	200 cm
Max. daily snowfall	24.6 cm	25.9 cm
No. of days exceeding snowfall of:		
20 cm	2	2
10 cm	9	4
Avg. snow on ground	21.1 cm	15.1 cm
Peak snow on ground	48 cm	54 cm
No. of days with freezing rain	3	3
Daily amounts of freezing rain	4.6 mm	1.7 mm
	5.1 mm	6.9 mm
	6.4 mm	2.0 mm

TABLE IV

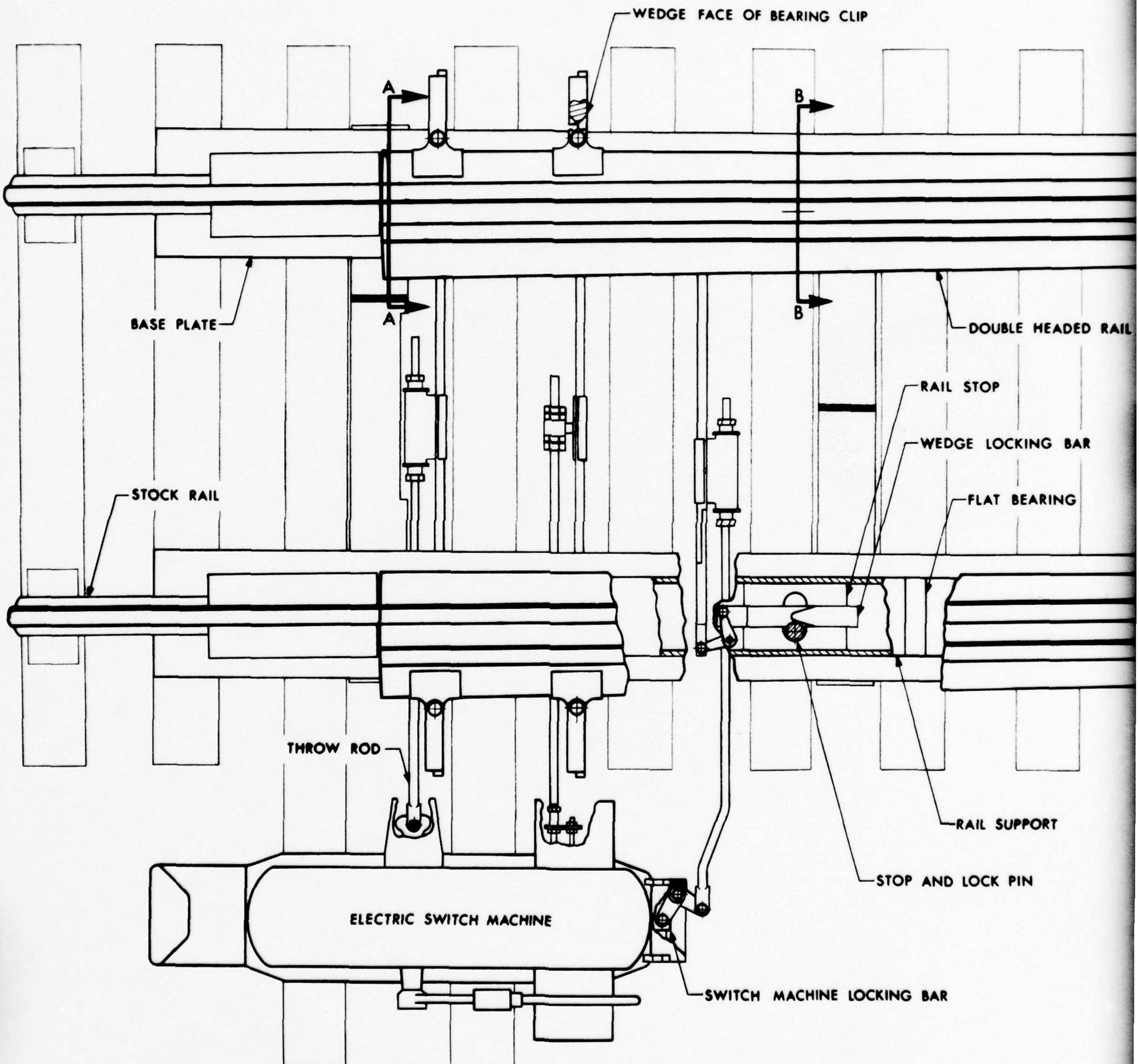
RAIL HEAD WEAR

RAIL	Head	Location	Surface Wear (mm)	Edge Burr (mm)
Left switch rail	Straight-through	Heel	0.53	0.71
		Middle	0.51	1.32
		Point	0.51	0.89
	Turnout	Heel	0.00	-- not measurable
		Middle	0.13	-- not measurable
		Point	0.25	-- not measurable
Right switch rail	Straight-through	Heel	0.25	0.51 to 0.76
		Middle	0.00	0.51
		Point	0.13	0.00 to 1.60
	Turnout	Heel	0.25	0.00 to 0.25
		Middle	0.13	0.74
		Point	0.13	0.51

TABLE V

RAIL HEAD HARDNESS

Rail	Head	Location	Rockwell "A" Hardness		Equivalent Brinnell No.	
			Field Tests	Lab. Tests		
Left switch rail	Straight-through	Heel	74A	71A	383	
		Middle	74A	70A	364	
		Point	73A	71A	383	
	Turnout	Heel	71A	71A	383	
		Middle	68A	72A	400	Overall Average
		Point	71A	72A	400	Rockwell 72A
Right switch rail	Straight-through	Heel	74A	74A	441	Brinnell 393
		Middle	68A	73A	419	
		Point	75A	71A	383	
	Turnout	Heel	60A	70A	364	
		Middle	56A	72A	400	
		Point	70A	72A	400	
Left stock Rail	--	Point	69A	--	--	
Right Stock rail	--	Point	72A	--	--	


WEDGE FACE OF BEARING CLIP
A
A
B
B
BASE PLATE
DOUBLE HEADED RAIL
RAIL STOP
WEDGE LOCKING BAR
FLAT BEARING
STOCK RAIL
THROW ROD
RAIL SUPPORT
STOP AND LOCK PIN
ELECTRIC SWITCH MACHINE
SWITCH MACHINE LOCKING BAR

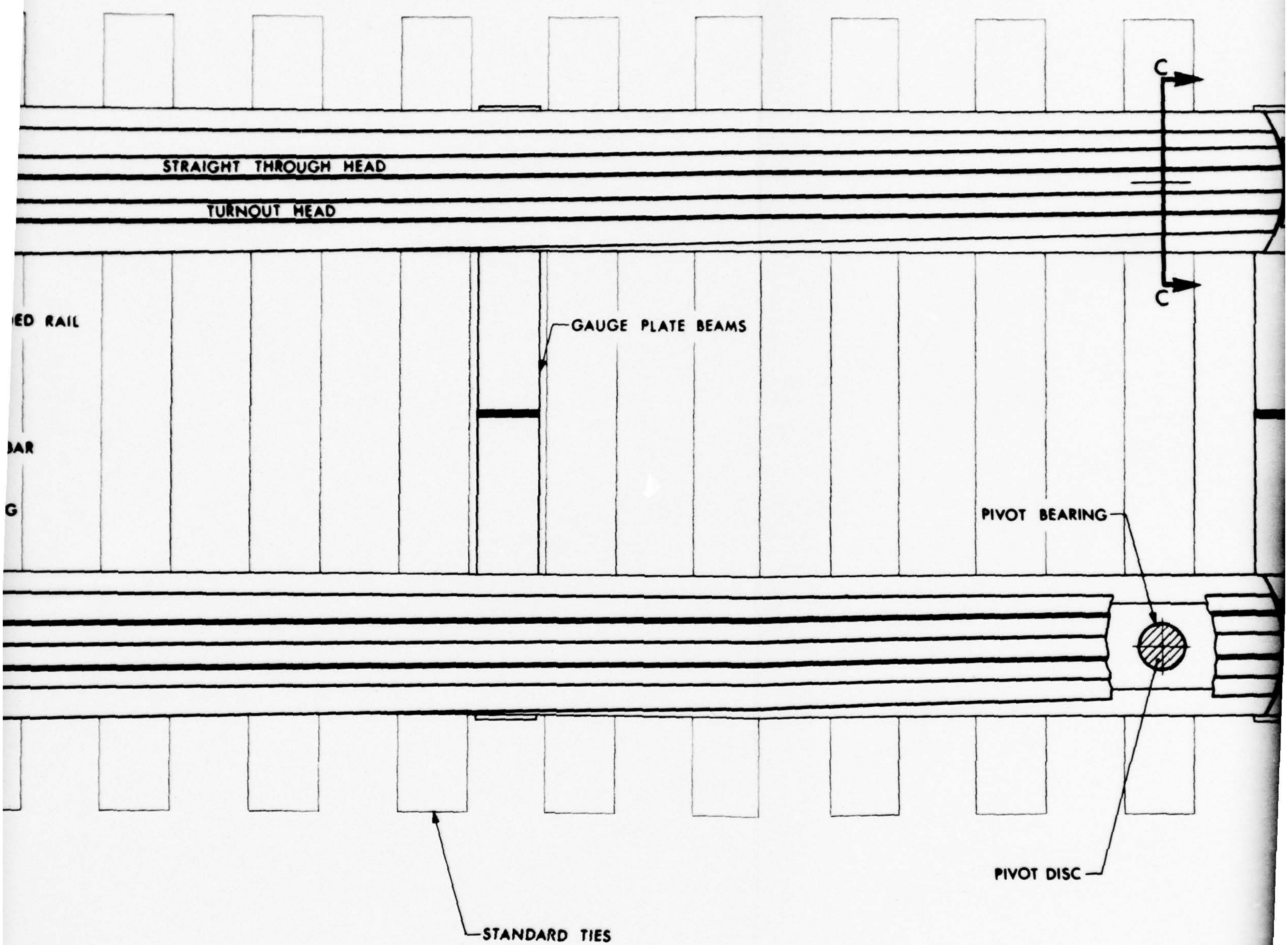


FIG. 1: 6.7 m HORIZONTAL T
FOR 52 kg A.R.E.A

2

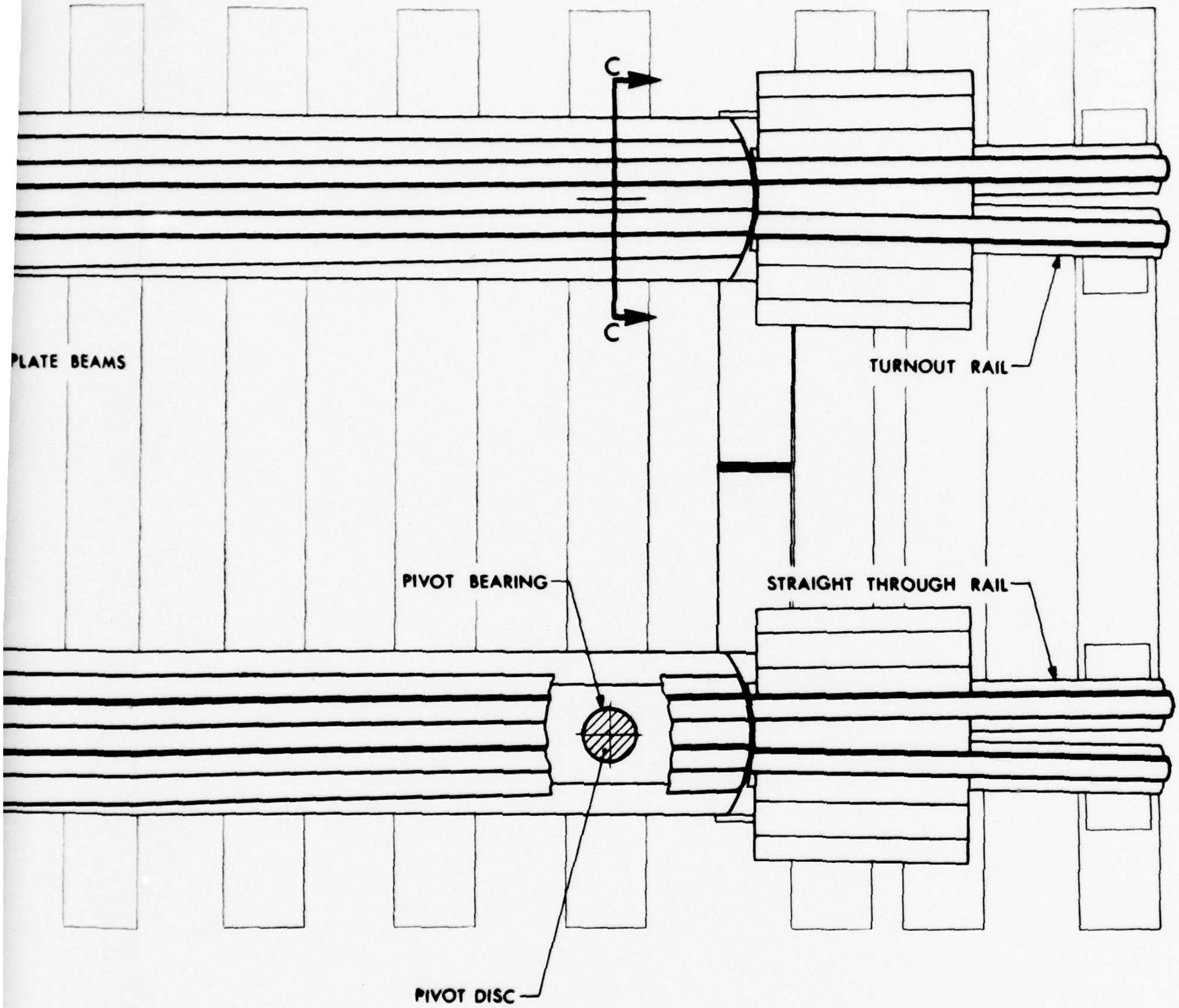


FIG. 1: 6.7 m HORIZONTAL TRAVERSE SWITCH
FOR 52 kg A.R.E.A. RAIL

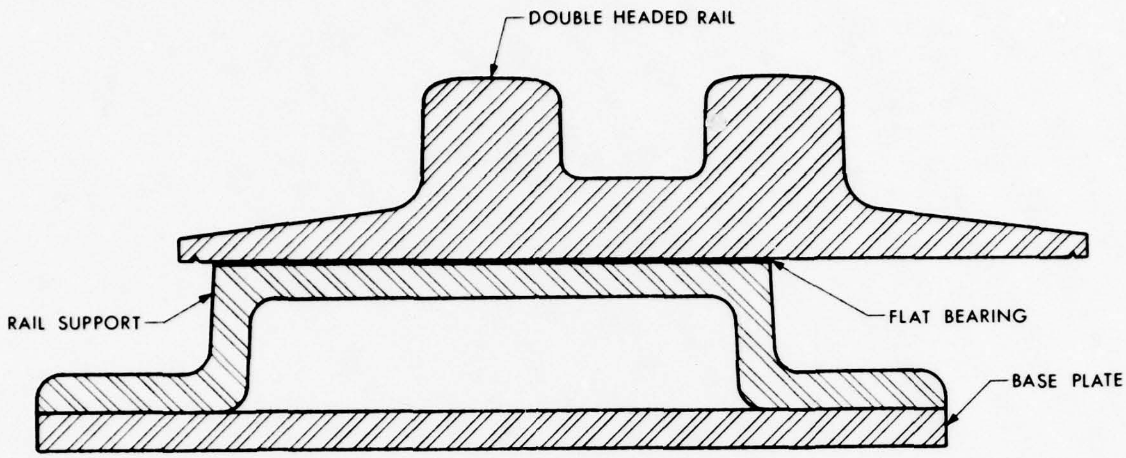


FIG. 1(a): SECTION A-A

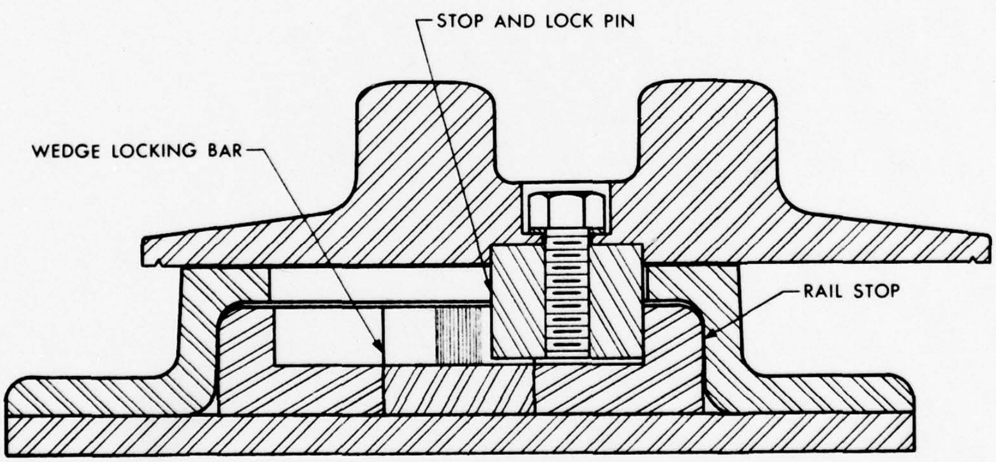


FIG. 1(b): SECTION B-B

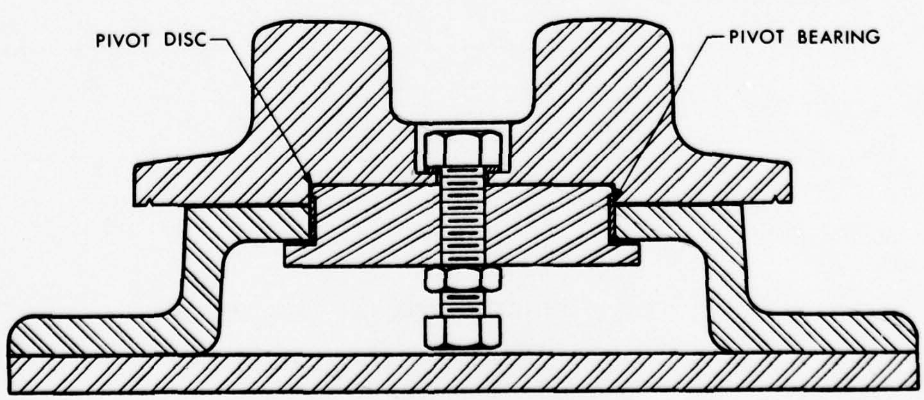


FIG. 1(c): SECTION C-C

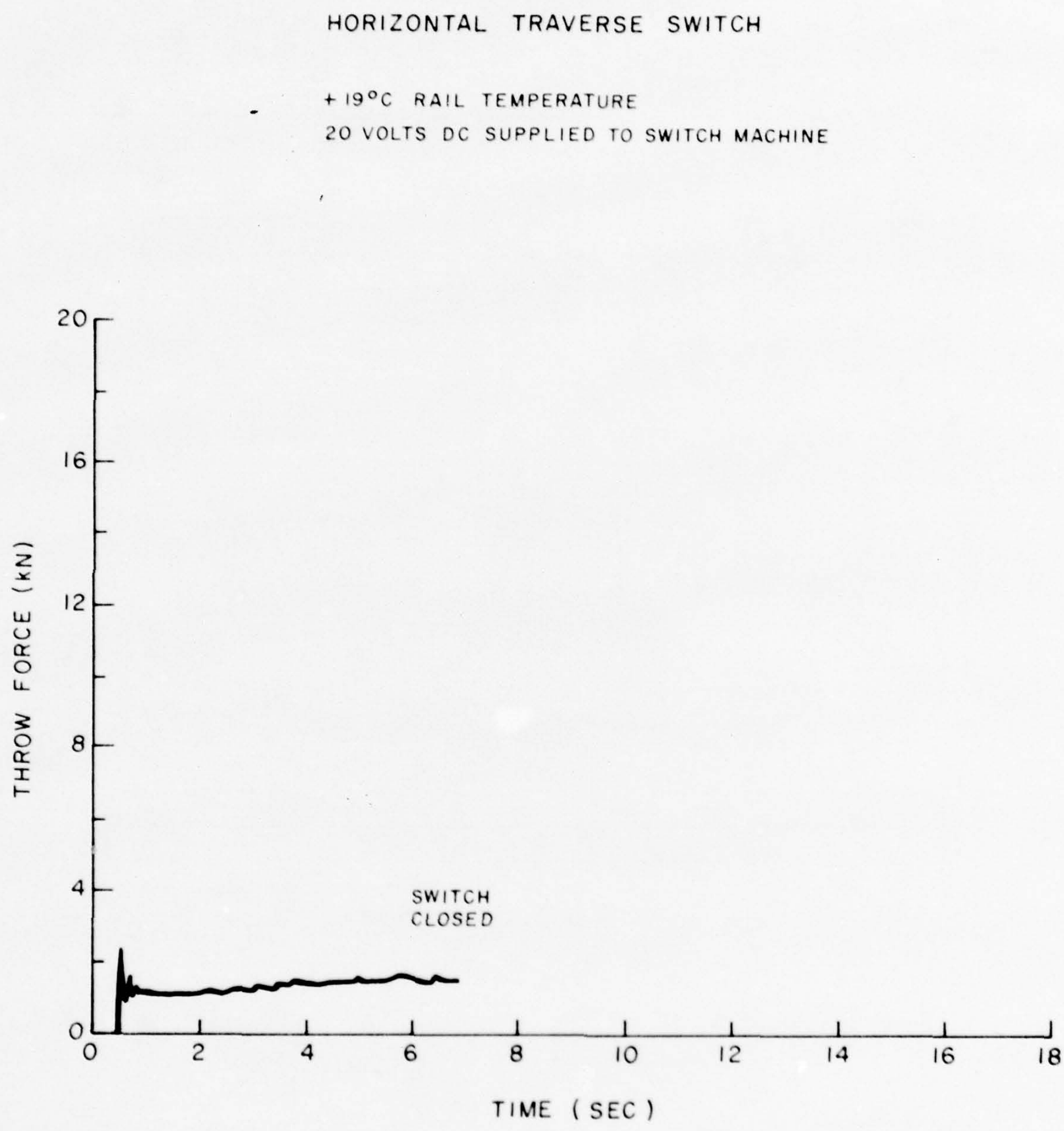


FIG. 2: FIRST THROW DRY AND WARM

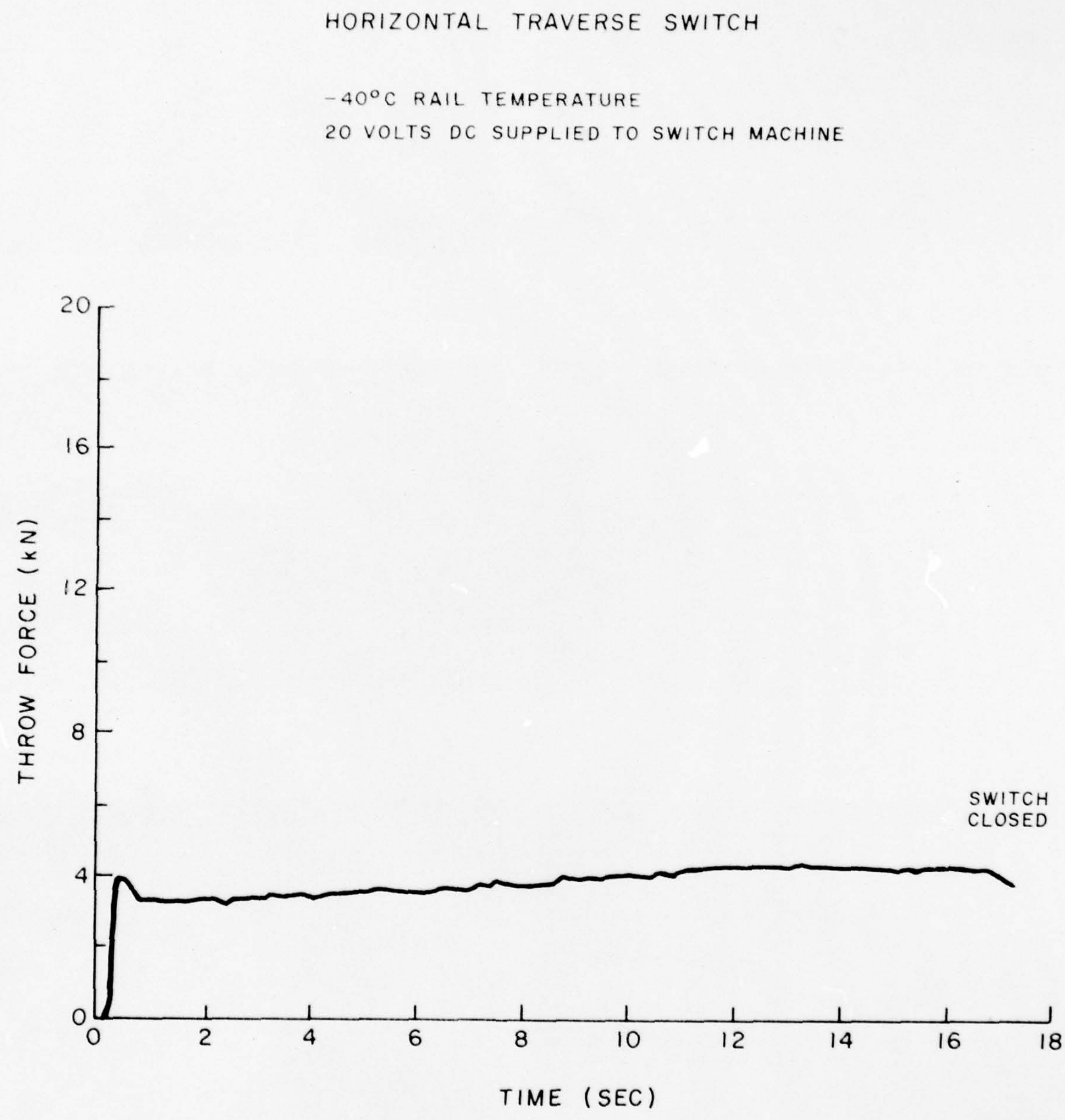


FIG. 3: FIRST THROW IN DRY COLD

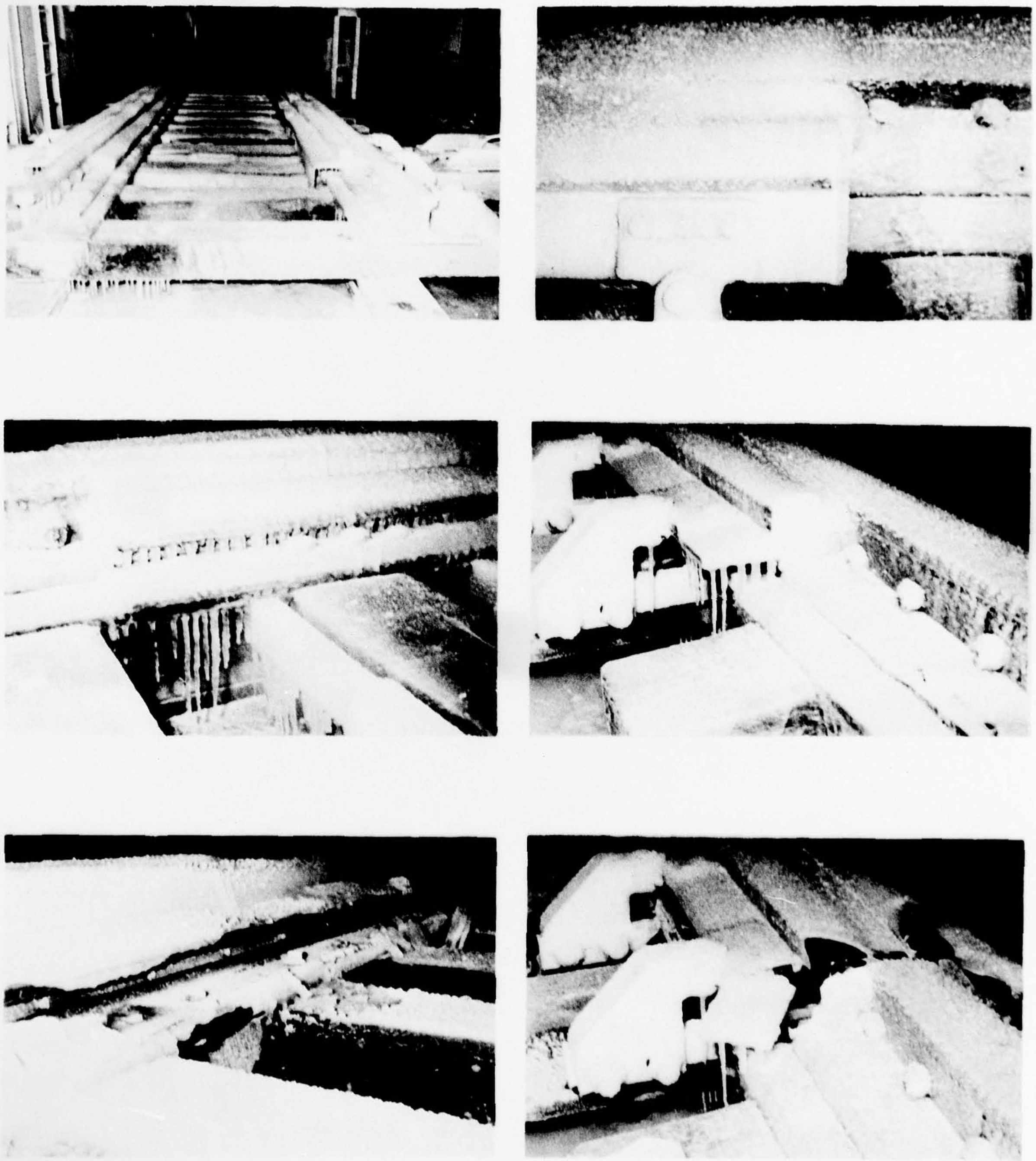


FIG. 4: TYPICAL ICE FROM FREEZING RAIN

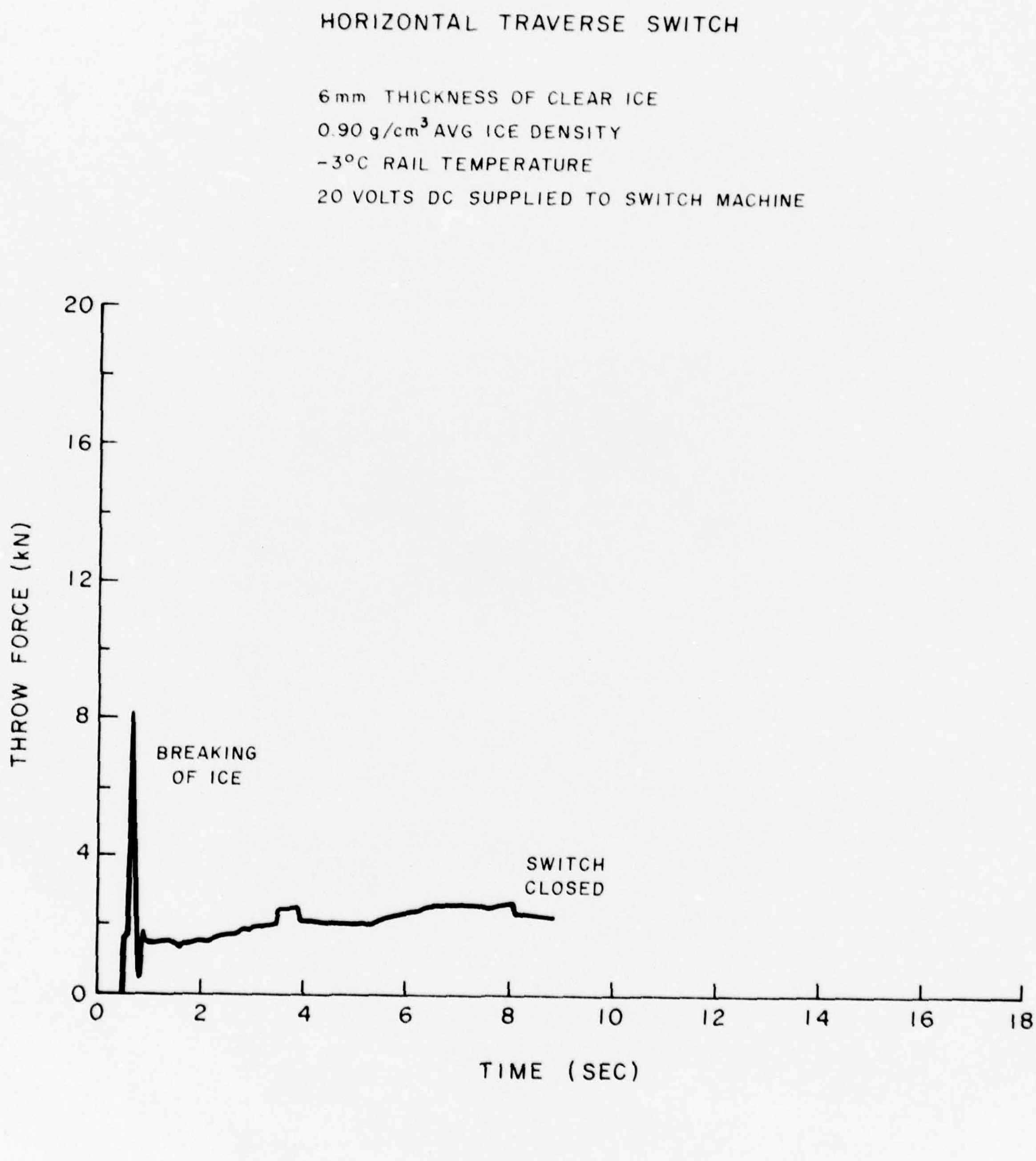


FIG. 5: FIRST THROW BREAKING ICE

FIG. 6: EXCEPTIONALLY SEVERE ICING FOR TEST NO. 127

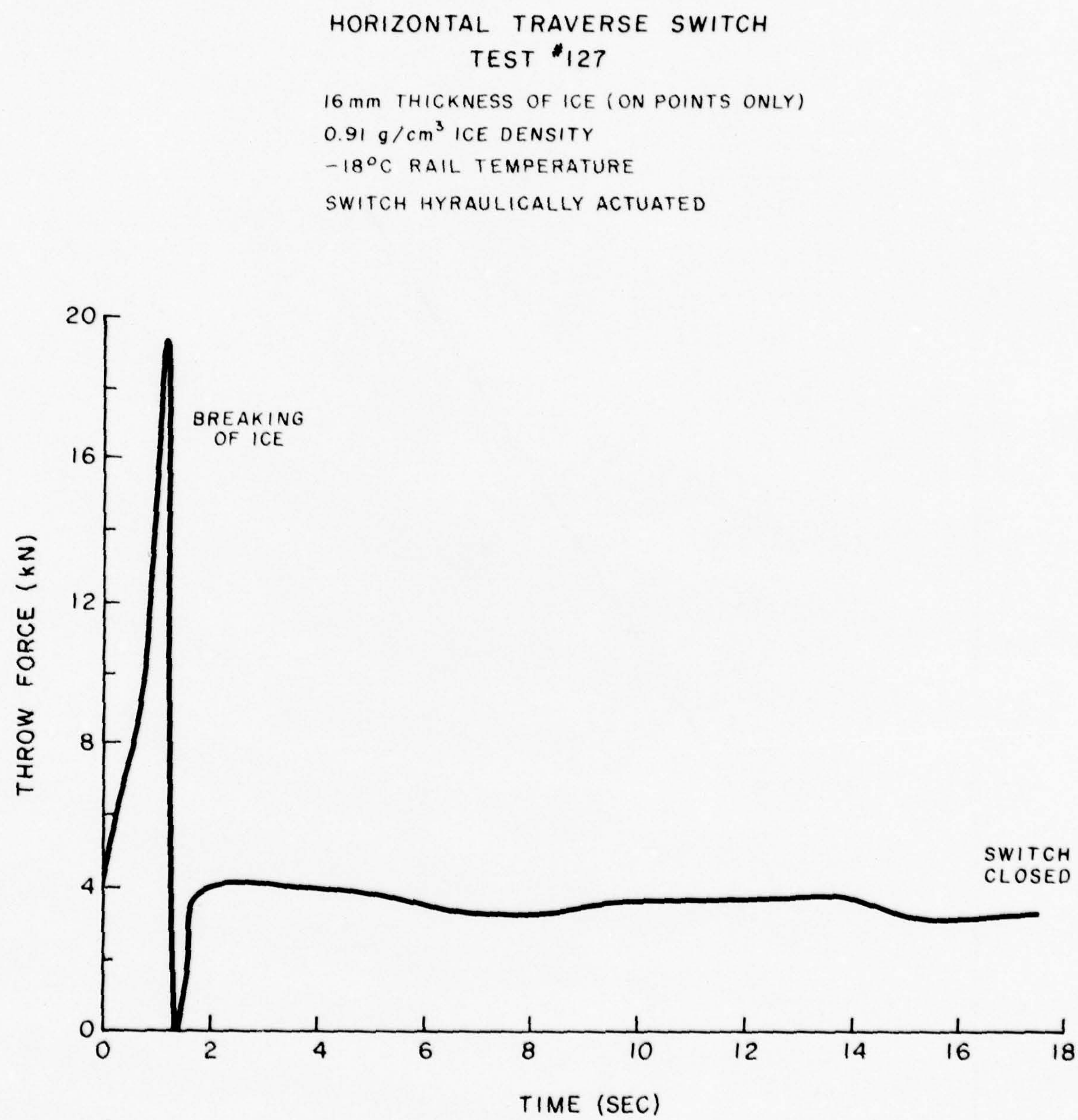


FIG. 7: FIRST THROW BREAKING CLEAR ICE

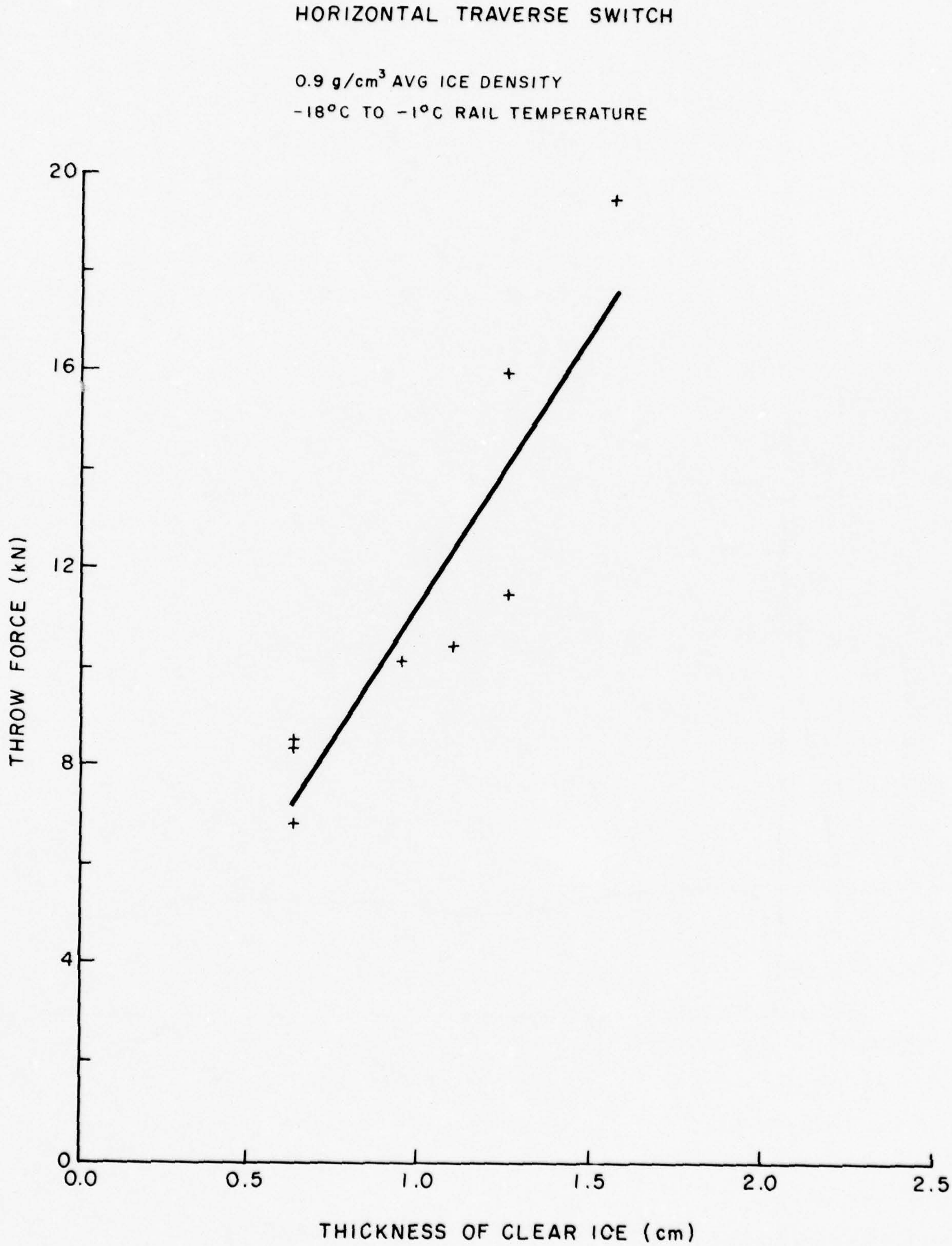


FIG. 8: INITIAL PEAK FORCE OF FIRST THROW BREAKING ICE

FIG. 9: TYPICAL HEAVY SNOWFALL AFTER THROWING SWITCH

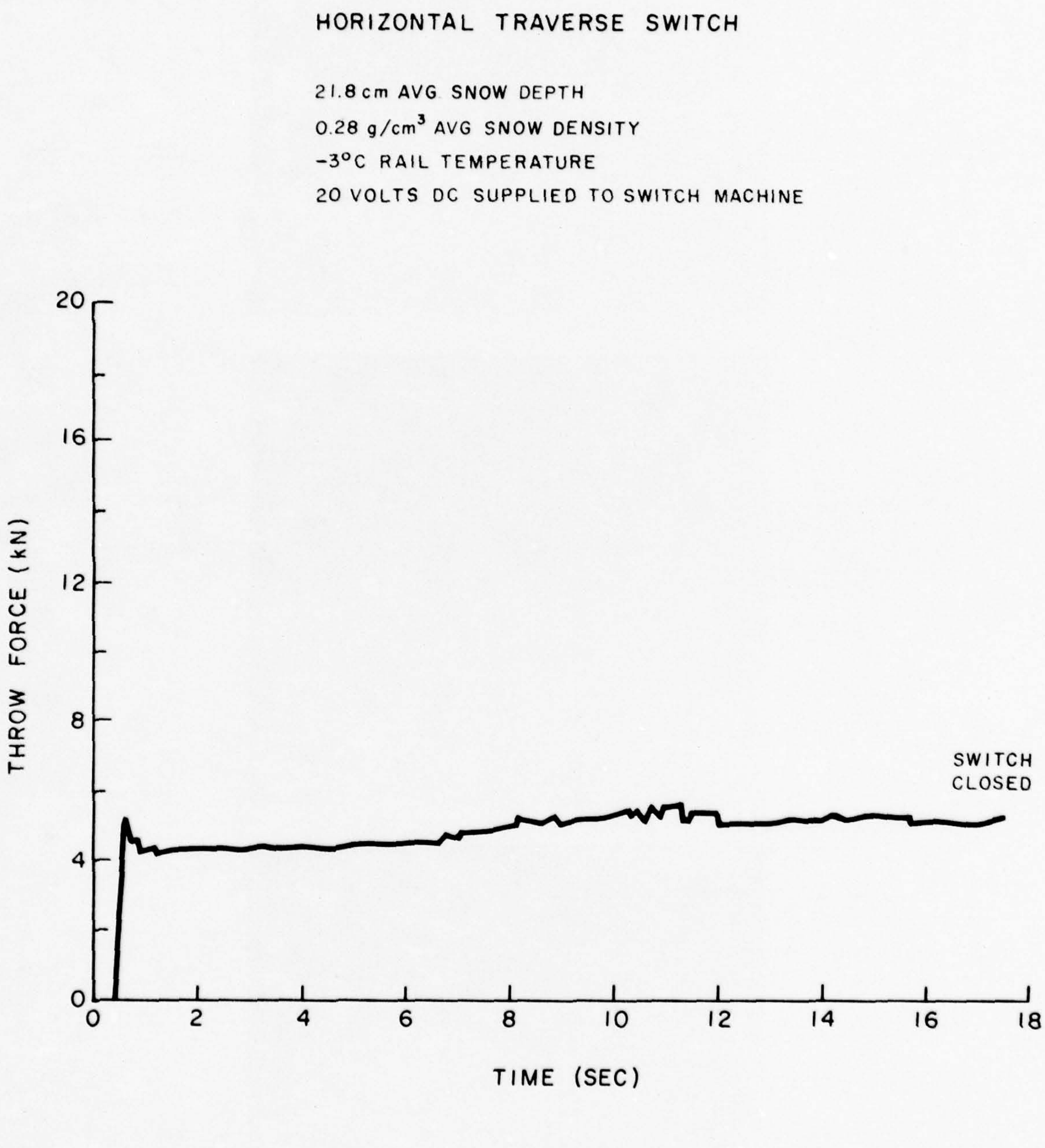


FIG. 10: FIRST THROW MOVING TYPICAL SNOW

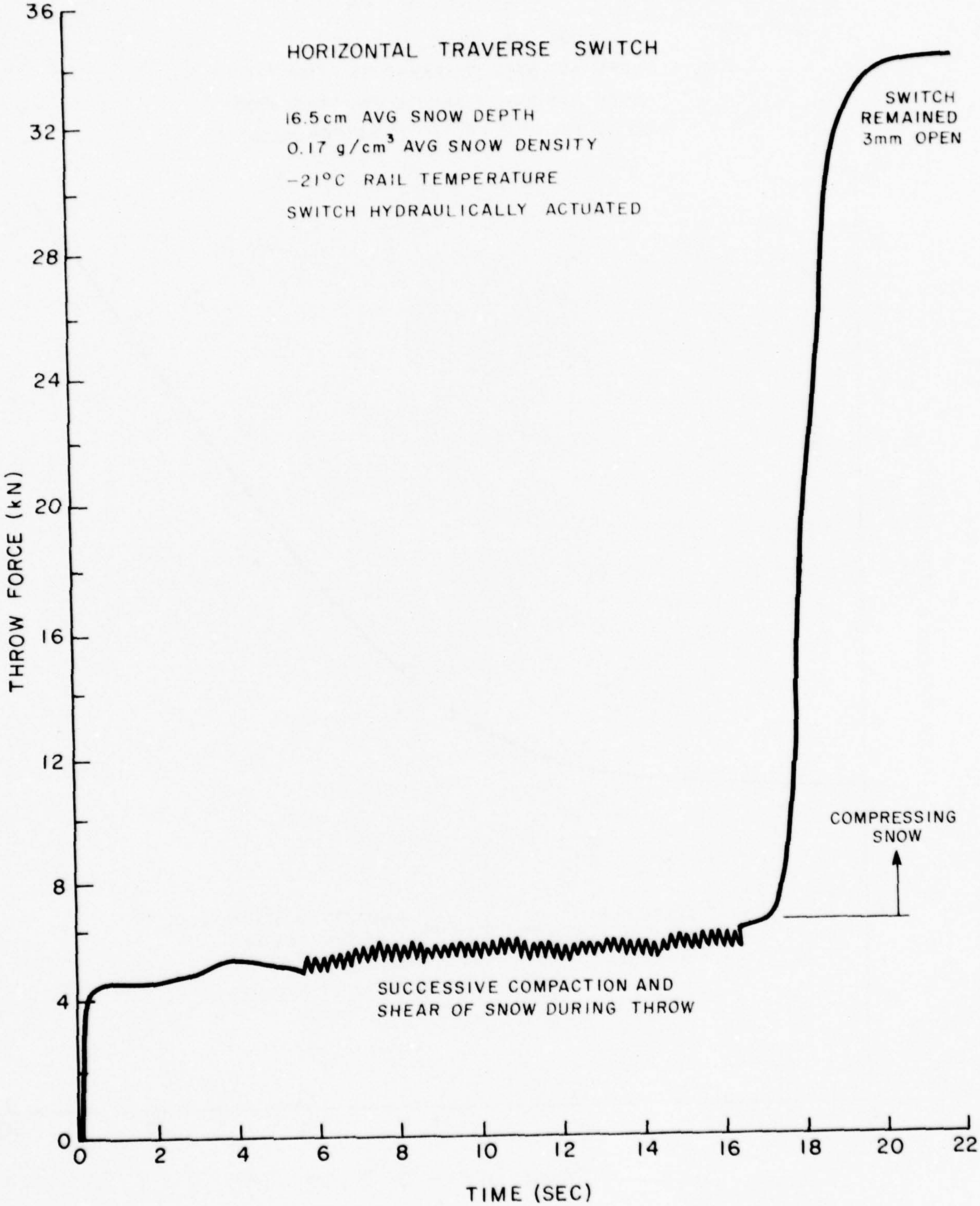


FIG. 11: FIRST THROW MOVING AND COMPRESSING SNOW

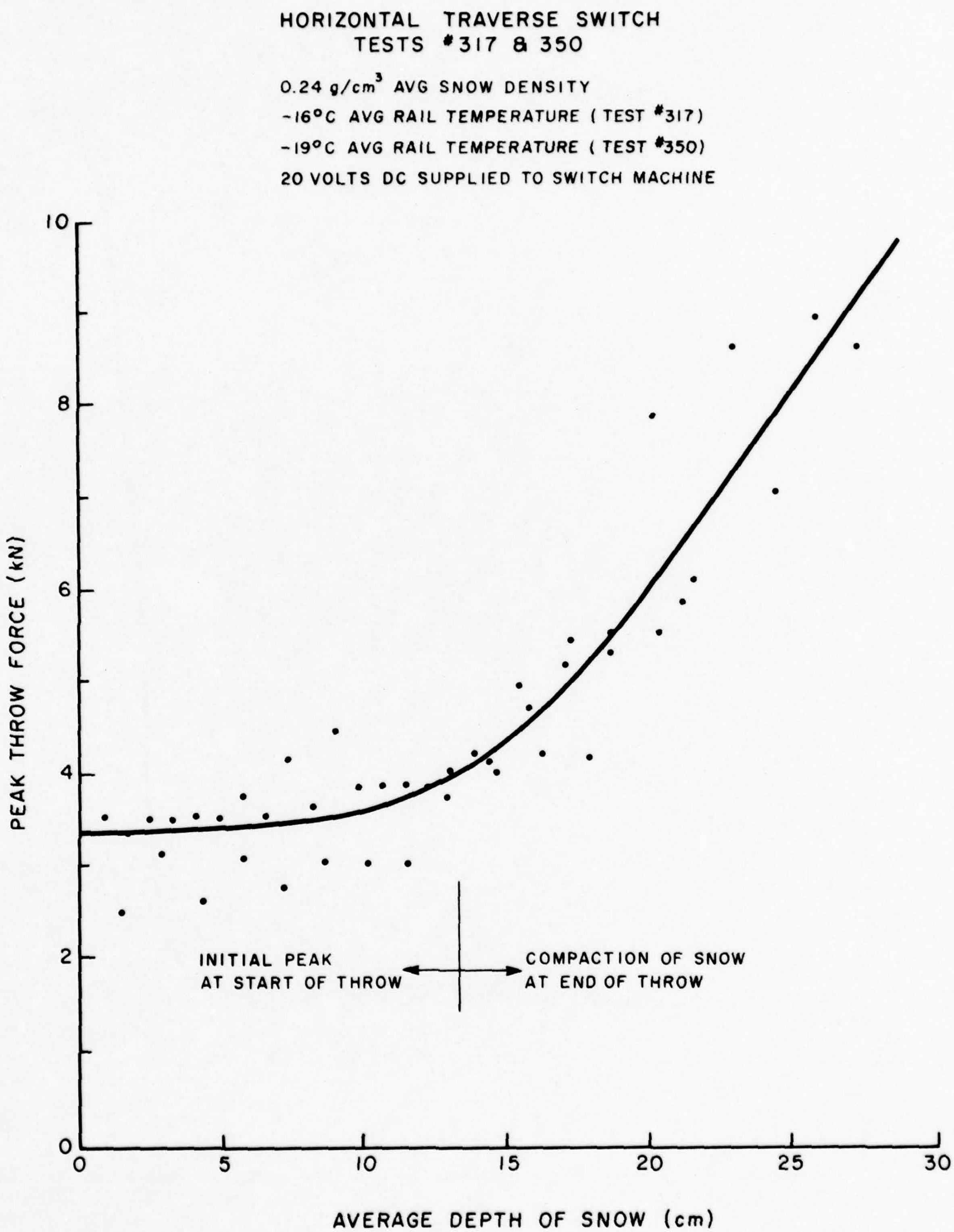


FIG. 12: PEAK THROW FORCE DURING CONTINUOUS SNOWFALL

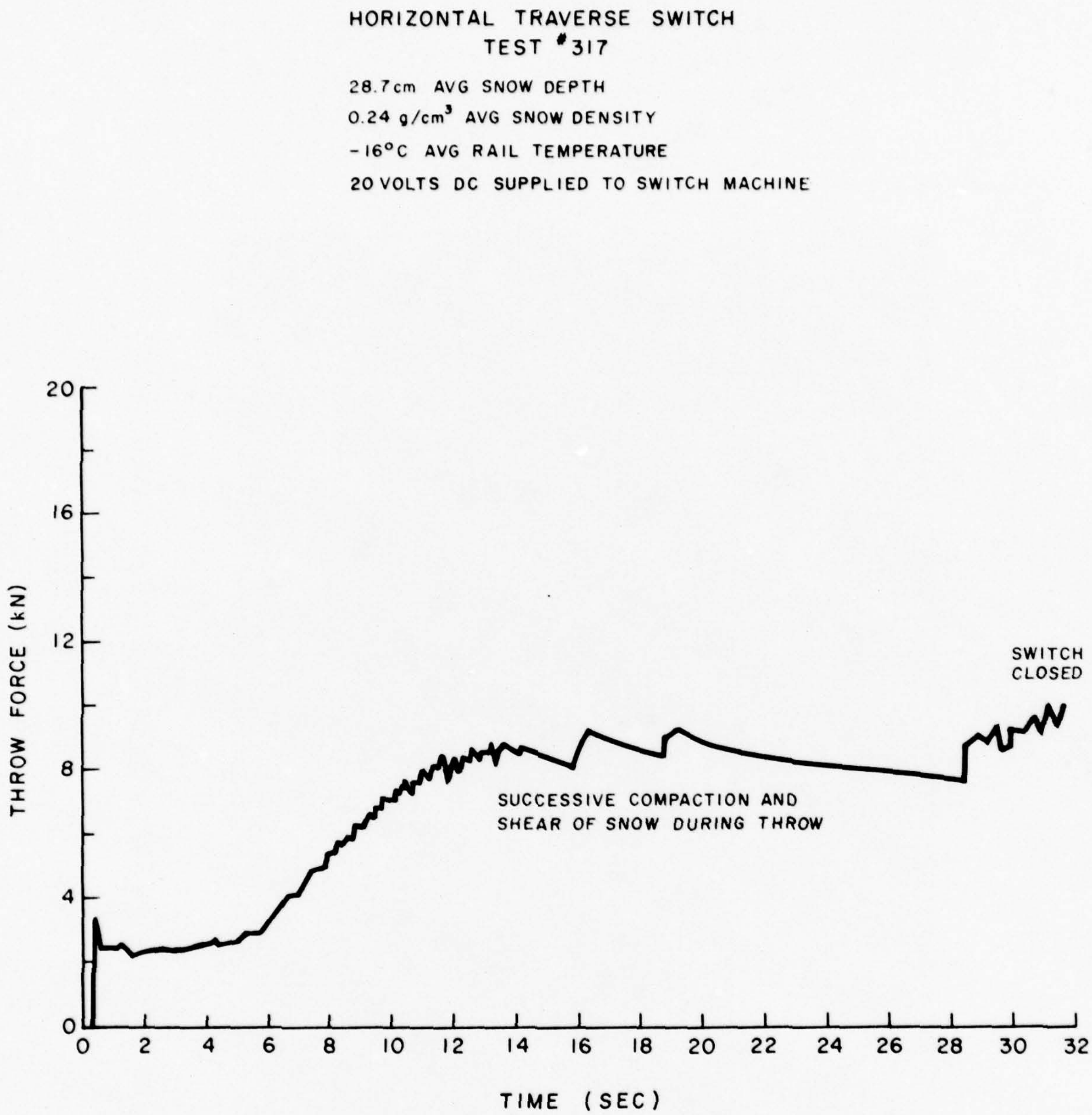


FIG. 13: LAST THROW DURING CONTINUOUS SNOWFALL

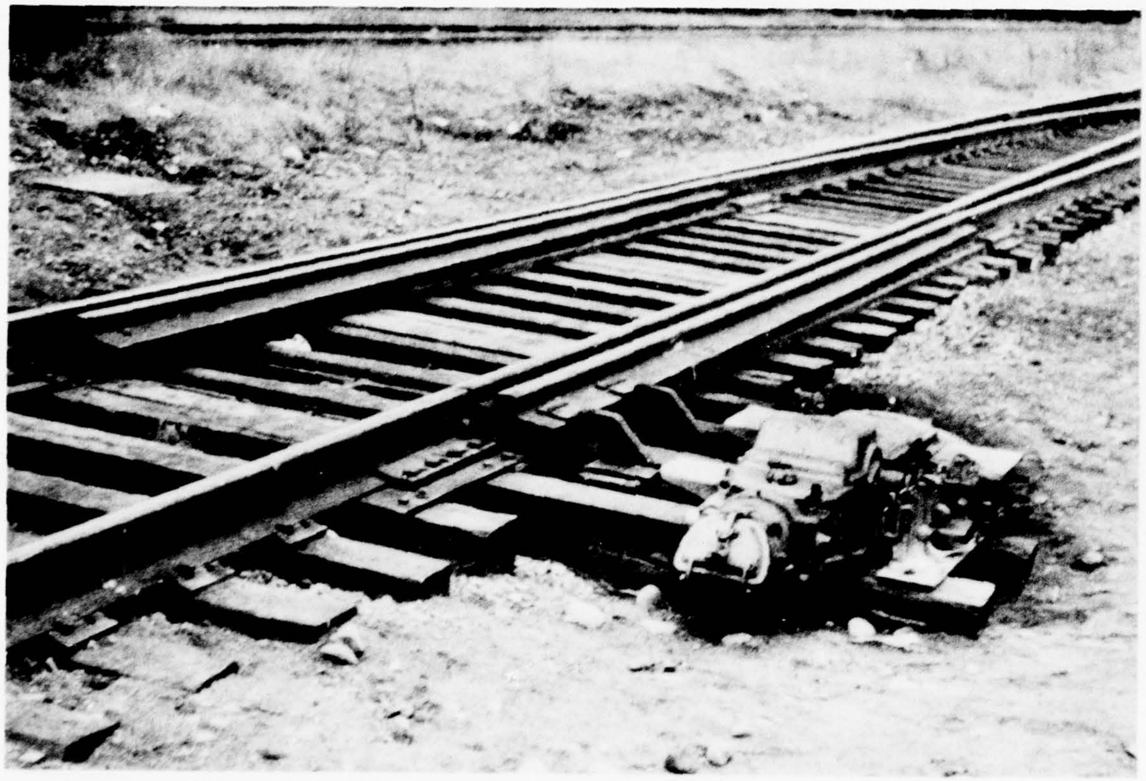
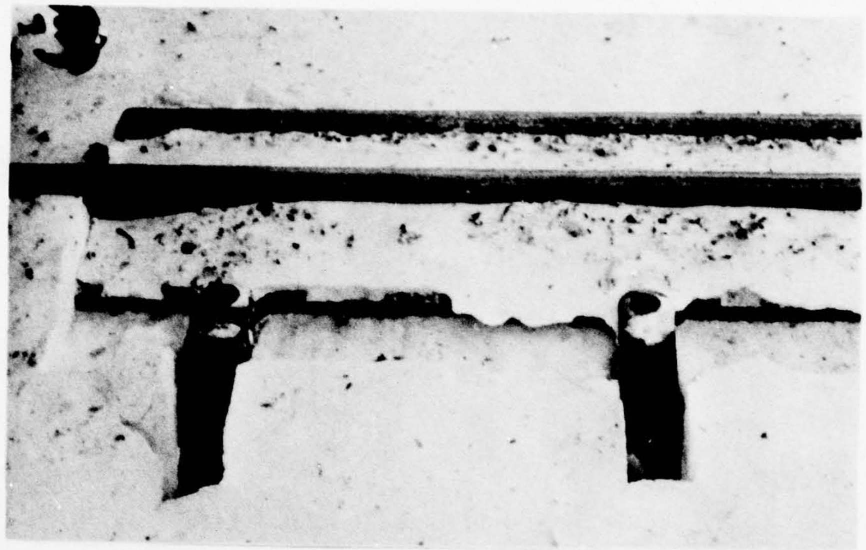
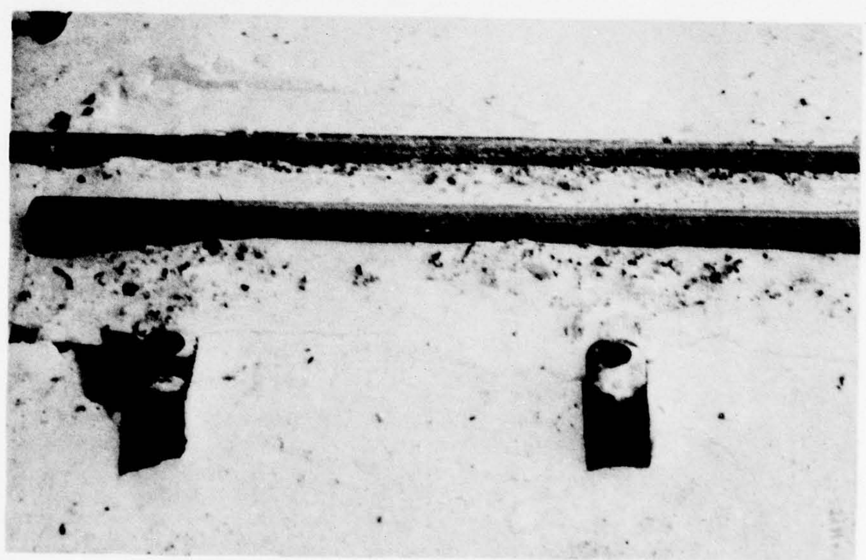


FIG. 14: HORIZONTAL TRAVERSE SWITCH, CP RAIL ST. LUC YARD

FIG. 15: HORIZONTAL TRAVERSE SWITCH CP RAIL ST. LUC YARD
JANUARY 1976

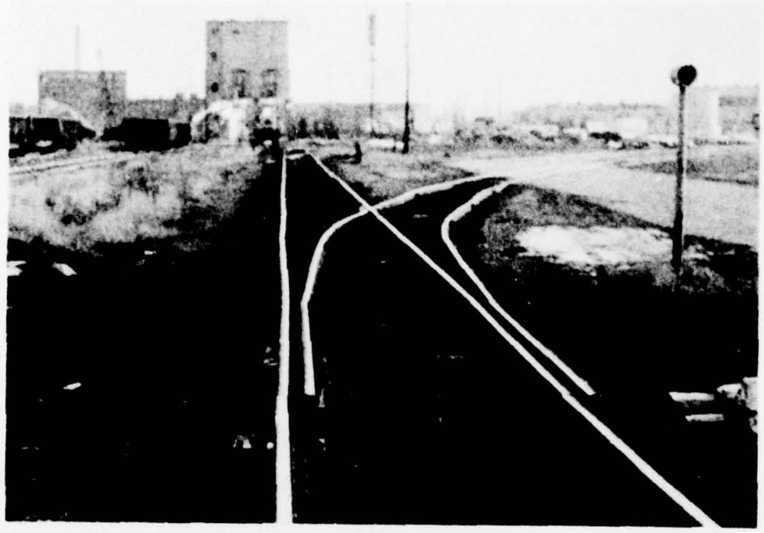


AFTER THROW IN UNDISTURBED SNOW

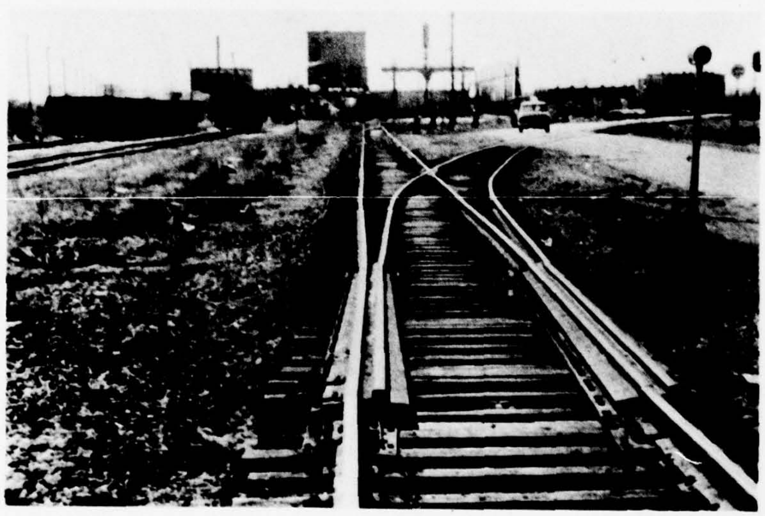


AFTER RETURN TO ORIGINAL POSITION

FIG. 16: THROWING SWITCH IN SNOW



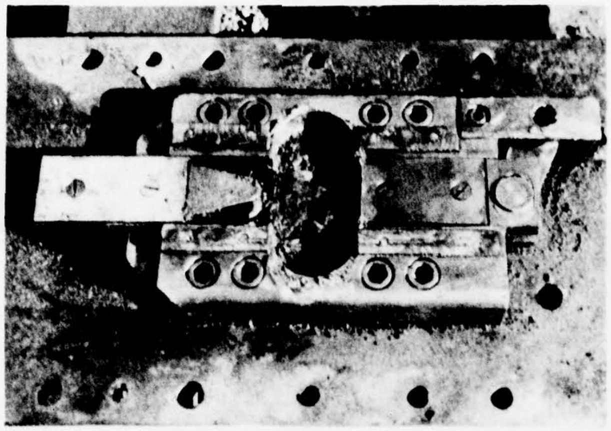
ALIGNMENT – NOVEMBER 1975



ALIGNMENT – APRIL 1976

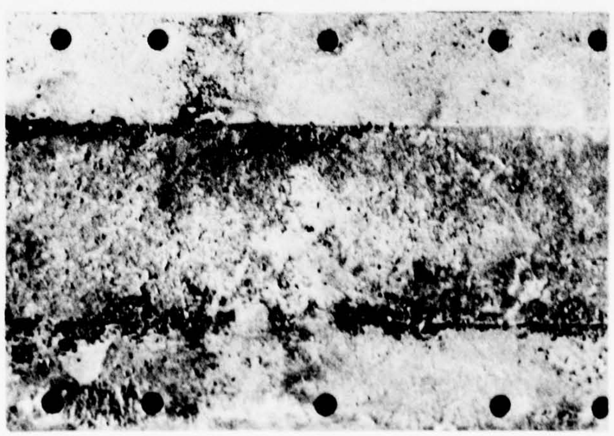
FIG. 17: ROTATION OF SWITCH

FIG. 18: DISPLACEMENT OF POINT END STOCK RAILS



(a) LOCKING MECHANISM

(b) PIVOT AND PIVOT BEARING



(c) BASEPLATE CORROSION

FIG. 19: INTERNAL COMPONENTS

APPENDIX A

A1.0 STRESSES IN SWITCH

A1.1 Test Method

Three cars and a diesel locomotive provided a variety of loading conditions at three different nominal speeds during a total of twelve measuring passes over the switch. Additional measurements were made when two diesels passed over the switch on their way to the diesel shop for service. From the strain measurements and the known modulus of elasticity of steel, the stresses in the switch were subsequently calculated.

A1.2 Strain Gauge Measurements

The strain gauges, bonded to the switch prior to its installation in track, were located where theoretical stress analysis had shown the highest stresses could be expected.

A1.3 Test Load

The test train consist was as follows:

CP Rail No.	Type	Load	Nominal Gross Weight
342418	gondola	rails	unknown
418432	14 m wheel flat	none	20,500 kg
339739	16 m gondola	tank "full" of tar	unknown
7012	diesel locomotive		104,000 kg

Each had four axles only. The two diesels were No. 6622 at 88,500 kg and No. 6508 at 90,000 kg again with four axles each.

A1.4 Test Runs

All test runs started from the point end with the locomotive trailing and returned from the heel end with the locomotive leading as per Table AI. From the nominal centre to centre distances of the locomotive trucks, 6.86 m for No. 7012 and 6.71 m for No. 6508, and the one second timing lines recorded on the charts, the actual speed for each run was subsequently calculated.

A1.5 Stress Analysis

The maximum simple bending stresses at each section were estimated from the calculated position of the neutral axis and extreme fibres and the measured position of the strain gauges. Where applicable, combined and principal stresses were estimated. All static stresses existing in the switch due to its own weight or due to irregularities in the supporting roadbed and ties were assumed to be negligible compared to the stresses induced by the car and locomotive loads. Because of the inaccuracies inherent in this method, the stresses were generally reported to the nearest 5 MPa.

After a cursory inspection of the recordings and preliminary stress calculations for each car and the locomotive for Run No. 1, it was decided that an adequate measure of the stresses in the switch could be obtained without detailed analysis of the stresses from the medium speed runs or of the stresses caused by the three cars during the other runs. For Runs No. 1 through 4 and 9 through 12 only the highest peak compressive and tensile stresses at each section were determined for the locomotive. From the three turnout runs, No. 3, 7, and 9, the effects of lateral thrust on the left switch rail were calculated.

Since the two locomotives of Run X were so similar in weight, the peak stresses for each wheel were determined. From this data the variations about the average stresses were determined and the highest stresses were extracted for inclusion with the data from Runs No. 1, 2, 11 and 12. The overall average variation was about ±20%.

For Runs No. 1, X and 11, the maximum simple bending stresses in the left rail at the locking device were calculated from the measurements of two separate strain gauges, one mounted above and the other below the neutral axis. Analysis of these results indicated that the method of extrapolating the measured data to obtain the maximum simple bending stresses would not impair the credibility of the results.

A1.6 Stresses in Double Headed Rails

Details of the stress measurements for the double headed rails are shown in Table AII. The highest simple bending stress of 105 MPa occurred at the top of the rail heads in longitudinal bending.

A1.6.1 Principal Stresses

"Vertical Shear" stresses were found to have no significant effect on the maximum principal stresses. Therefore, except for those cases involving lateral bending, the simple bending stresses were essentially the principal stresses. On turnout at 21.4 km/h the combination of lateral bending and longitudinal bending resulted in a maximum principal stress at the locking device in the left inside rail head of 105 MPa tension and in the bottom outside corner of the rail flange of 90 MPa compression.

A1.7 Stresses in Rail Supports

Assuming that the rail support and baseplate bend as two independent bodies (the most conservative condition), details of the resulting stresses for the rail supports are shown in Table AIII. The highest stress of 90 MPa occurred at the base of the section midway between the locking device and the pivot.

A1.8 Stresses in Baseplates

On the assumption that the maximum stress in the baseplates would occur just beyond the point end of the rail support, details of the baseplate stresses are shown in Table AIV. The highest stress measured was 70 MPa.

TABLE AI

SWITCH STRESSES TEST RUNS

Run No.	Switch Direction	Travel from	Locomotive	Nominal Speed
1	straight-through	point	trailing	8 km/h
2	return	heel	leading	8 km/h
3	turnout	point	trailing	8 km/h
4	return	heel	leading	8 km/h
X	straight-through	point	2 diesels	--
5	straight-through	point	trailing	16 km/h
6	return	heel	leading	16 km/h
7	turnout	point	trailing	16 km/h
8	return	heel	leading	16 km/h
9	turnout	point	trailing	24 km/h
10	return	heel	leading	24 km/h
11	straight-through	point	trailing	24 km/h
12	return	heel	leading	24 km/h

TABLE AII

STRESSES IN DOUBLE HEADED RAILS

Simple Longitudinal Bending

The highest stresses occurred at the top of the rail heads.

Stress @	Load @	Switch Direction	Rail	Stresses (MPa)* Avg. Peak	High Peak	Remarks
locking device	point	straight-through	left	+60	+75	Highest when all wheels of one truck are on switch.
			right	+35	+40	
		turnout	left	+60	+90	
			right	+35	+40	
	locking device	straight-through	left	-30	-35	
			right	-50	-55	
		turnout	left	-20	-20	
			right	-70	-85	
pivot	pivot	straight-through	left	-95	-105	← Highest stresses in switch.
			right	-50	-55	
		turnout	left	-60	-70	
			right	-70	-85	
	heel	straight-through	left	+90	+105	
			right	+55	+70	
		turnout	left	+55	+70	
			right	+75	+90	

Simple Transverse Bending

The highest stresses occurred at the root of the flange.

Stress @	Load @	Switch Direction	Rail	Stresses (MPa)* Avg. Peak	High Peak	Remarks
near locking device		straight-through	left	±20	±30	
		turnout	right	±60	±70	

Simple Lateral Bending

The highest stresses occurred on the outside edges of the left rail flange.

Stress @	Load @	Switch Direction	Speed (km/h)	Peak Stress* (MPa)	Remarks
locking device	0.6 m from point	turnout	11.1	±10	
			17.4	±22	
			21.4	±30	

* +ve = tension   -ve = compression

TABLE AIII

STRESSES IN RAIL SUPPORTS

Simple Longitudinal Bending

Stress @	Load @	Switch Direction	Rail Support	Stresses (MPa)* Avg. Peak	Stresses (MPa)* High Peak	Remarks
locking device	point	straight-through	left	+30	+30	
			right	+20	+30	
		turnout	left	+20	+30	
			right	+20	+20	
	locking device	straight-through	left	-30	-35	
			right	-20	-30	
		turnout	left	-30	-35	
			right	-20	-30	
pivot	heel	straight-through	left	+35	+35	
			right	+50	+75	
		turnout	left	+40	+40	
			right	+70	+70	
midway between locking device and pivot		straight-through	left	+85	+90 ←	Highest stresses in rail support
			right	+40	+55	
		turnout	left	+55	+60	
			right	+60	+60	

Simple Transverse Bending

Of the four strain gauges mounted to measure transverse bending stresses in the top of the rail support section, two were unserviceable before the start of testing, one was electrically shorted as the load was applied, and the final one produced unreadably small deflections on the chart.

* +ve = tension -ve = compression

TABLE AIV

STRESSES IN BASEPLATES

Simple Longitudinal Bending

It was assumed that the maximum stress would occur just beyond the point end of the rail support.

Stress @	Load @	Switch Direction	Base-Plate	Stresses (MPa)* Avg. Peak	Stresses (MPa)* High Peak	Remarks
Just beyond point end of rail support		straight-through	left	±60	±70	
			right	±70	±70	
		turnout	left	±60	±60	
			right	±70	±70 ←	Highest stresses in baseplate.

* +ve = tension -ve = compression

CURRENT PROJECTS

Much of the work in progress in the laboratories of the National Aeronautical Establishment and the Division of Mechanical Engineering includes calibrations, routine analyses and the testing of proprietary products; in addition, a substantial volume of the work is devoted to applied research or investigations carried out under contract and on behalf of private industrial companies.

None of this work is reported in the following pages.

ANALYSIS LABORATORY

AVAILABLE FACILITIES

This laboratory has analysis and simulation facilities available on an open-shop basis. Enquiries are especially encouraged from industry for projects that may utilize the facilities in a novel and/or particularly effective manner. Such projects are given priority and are fully supported with assistance from laboratory personnel. The facilities are especially suited to system design studies and scientific data processing. Information is available upon request.

EQUIPMENT

An Electronic Associates 690 HYBRID COMPUTER consisting of the following:

(a) PACER 100 digital computer

- 32K memory
- card reader
- high speed printer
- disc
- digital plotter
- Lektromedia interactive terminal

(b) Two EAI 680 analogue computer consoles

- 200 amplifiers including 60 integrators
- 100 digitally set attenuators
- non-linear elements
- x-y pen recorders
- strip chart recorders
- large screen oscilloscope

(c) EAI 693 interface

- 24 digital-to-analogue converters
- 48 analogue-to-digital converters
- interrupts, sense lines, control lines

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Dual channel real time portable spectrum analyser, Hewlett Packard Model 3582A. Bandwidth 0.02 to 25.5 Hz. Built-in periodic and random sources for transfer function and transient signal analysis.

GENERAL STUDIES

A microprocessor-based function generator for the hybrid computer is being designed. A TI 9900 development system has been obtained to be used for the project.

A study is being made on the use of topological methods to describe and analyze complex system.

APPLICATION STUDIES

Aviation Electric Ltd. hybrid computer modeling work is continuing in support of their advanced control concepts for both the small business jet engine and the helicopter engine.

Canadian Westinghouse Ltd. are continuing a study of fuel controller requirements for a new family of industrial gas turbines. A hybrid computer model is being used to evaluate control system hardware.

In collaboration with Kendall Consultants Ltd., and SPAR Aerospace Products Ltd., a hybrid computer model of the remote manipulator arm for the space shuttle is being assembled. The model includes all allowable motions in three dimensions as well as arm flexibility effects. The three dimensional model is complete and arm control algorithms aer being evaluated.

In collaboration with the Railway Laboratory, a pilot hybrid computer model of the NRC roller rig for railway vehicle testing is being used as an aid in the design of the roller rig and its controls.

In collaboration with the Control Systems and Human Engineering Laboratory and the International Nickel Co., Ontario Division, an interactive computer model of a copper-nickel smelter is being developed to study material handling and scheduling in the plant.

In collaboration with DME Engine Laboratory a study is being made to develop a computer model of air cushion vehicles.

In collaboration with DME Engine Laboratory analysis of fuel consumption and travel time of test cars with two computer controlled traffic light sequencing plans.

In collaboration with Glenayre Electronics Ltd. and Lornex Mines a computer model of open pit mining operations is being developed for use in the design and evaluation of a truck dispatching system.

A joint project with DND and Davis Eryou and Associates to evaluate ULTRA Controller hardware using a hybrid computer model of the DDH 280 Propulsion Machinery.

In co-operation with Carleton University and Engine Laboratory a preliminary study is underway of a heavy equipment propulsion system using a co-rotating compressor.

In collaboration with Stephens-Adamson of Belleville a hybrid computer model of long conveyor belts is being assembled.

In collaboration with Davis Eryou and Associates a hybrid computer model of an automobile is being assembled.

A joint project with ARCTEC Canada and Davis Eryou and Associates for reduction and analysis of oceanographic and ice breaking ship trials data is being carried out on the hybrid computer.

A hybrid computer model of high voltage impulse measuring systems is being developed by the Power Engineering Laboratory of the Division of Electrical Engineering.

SYSTEM SOFTWARE STUDIES

A preprocessor for hybrid computer model digital programs.

Character string manipulation routines to be used in a Fortran environment.

CONTROL SYSTEMS AND HUMAN ENGINEERING LABORATORY

INDUSTRIAL CONTROL PROBLEMS

In collaboration with the Analysis Laboratory interactive computer models are being developed and applied to a variety of scheduling and materials handling projects in the mining and metal processing industries.

Application of microprocessors to improve quality, performance and efficiency in the metal forming industry is currently being undertaken in collaboration with a Canadian company.

To study distributed process control a network software system (DECNET) is being installed to connect together the PDP-11/45 and PDP-11/60 computers in the Laboratory. Also, a serial communication system based on the HDLC line protocol is being implemented with microprocessors. This activity is proceeding in parallel with the development of an international standard for industrial intersubsystem communication.

A flowmeter, viscometer, consistency sensor and control valve utilizing radial laminar flow have been developed and patented. The devices, currently under test for industrial application, are mechanically simple and have a minimum of machining tolerances. They offer significant advantages over those currently available in that the maintenance of laminar flow provides quiet operation while allowing accurate performance production.

ADVANCED TRANSPORTATION CONCEPTS

The conceptual design for a high speed intercity magnetically levitated and linear synchronous motor propelled vehicle plus elevated guideway system as based on the results of a basic Maglev research program jointly conducted by Queen's University, University of Toronto and McGill University has been carried out in collaboration with Transport Canada. Ongoing study includes computer modeling for ride quality assessment, vehicle dynamic behaviour prediction and engineering design consideration of the magnets.

HUMAN ENGINEERING – BEHAVIOURAL STUDIES

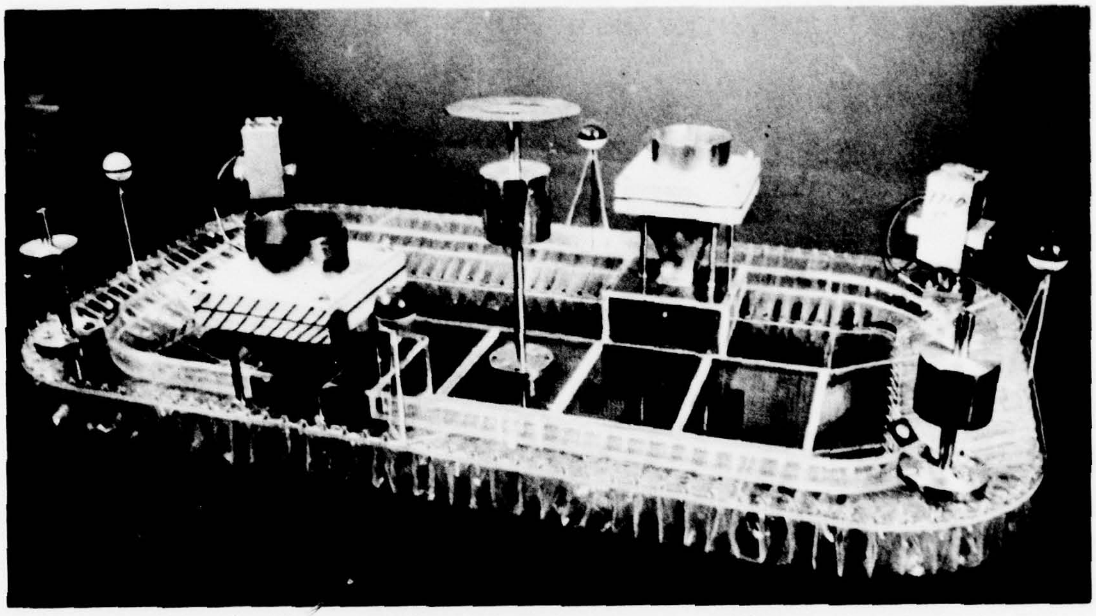
The investigation of the effect of internal and external environments on human psychomotor performance has been extended to Ministry of Transport radio communications staff operating in the high Arctic under conditions of continuous darkness. A study is also being conducted in collaboration with Indian Air Force on the psychomotor performance of aircrew on long range flights.

Tracking experiments have been designed and initiated in the series dealing with precision of movement to a target. These are further tests of the hypothesis that subjects move in a frame of reference based on proprioceptive rather than visual information.

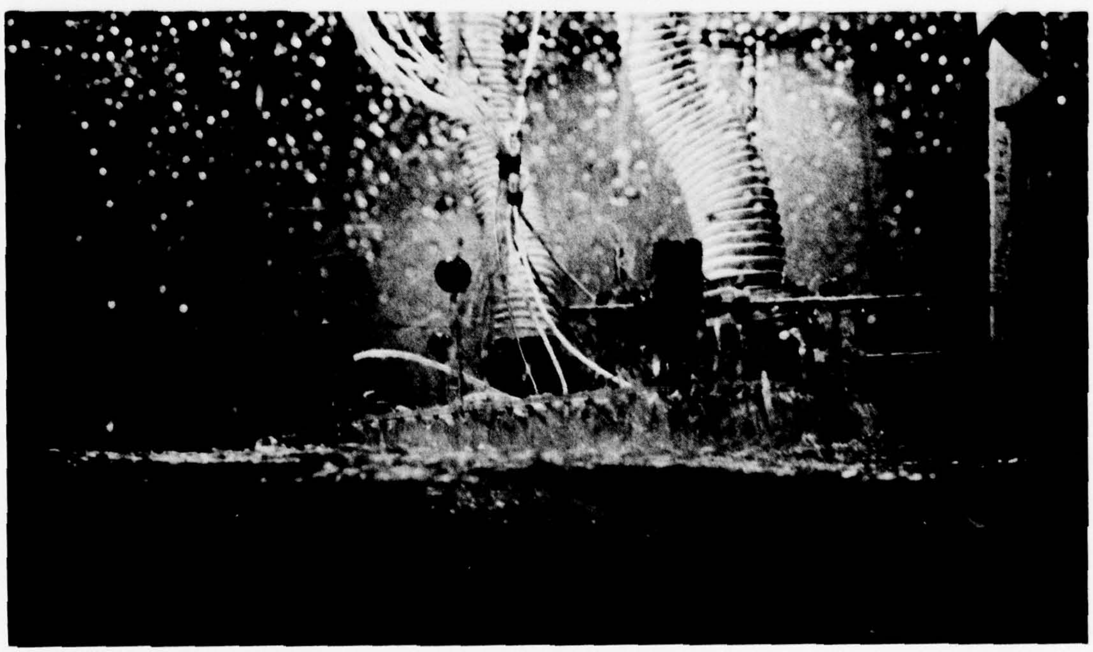
HUMAN ENGINEERING – MEDICAL AND SURGICAL

A production model portable thermoelectric cooling system is being developed in collaboration with the Montreal Neurological Institute for controlled cooling of the exposed spinal cord at operation.

A prototype model miniature instrument for measuring the viscoelastic properties of skin is being developed.



(a) THE TRANSPARENT PLASTIC MODEL OF A TYPICAL A.C. FERRY, WITH LIFT-AIR FEED DUCTS, DRAG TRANSDUCERS, ATTITUDE MARKERS AND BALANCE WEIGHTS INSTALLED.



(b) THE MODEL RUNNING AT SIMULATED 9.0 km/hr, SEEN FROM WATER LEVEL, TO SHOW THE UNDERWATER SKIRT AND BUBBLE PROFILE.

EXPERIMENTS ON A MODEL AIR CUSHION FERRY IN A WATER-FLOW CHANNEL

ENGINE LABORATORY
DIVISION OF MECHANICAL ENGINEERING

ENGINE LABORATORY

HOSPITAL AIR BED

The NRC Cairbed Mark I designed and built by NRC is being used by a hospital in Kingston, Ontario, to conduct a clinical study. Use of the bed has shown advantages over conventional support methods and has allowed better definitions of performance requirements needed for skin healing. A novel support air bag structure has been successfully tested.

Four advanced air beds, close to commercial design, will be manufactured under contract, and evaluated in use to verify the design.

GAS TURBINE OPERATIONS

Further investigative tests on a J85-CAN-15 gas turbine have continued. Studies have been made to assess the effects of down-trimming fuel flow on engine performance in both steady-state and transient modes of operation. Also examined was engine operation with a new proposed variable exit nozzle rigging procedure, which is intended to promote smoother afterburner initiation.

AEROACOUSTICS

As part of a study of noise characteristics of centrifugal fans and blowers, experiments to study impeller blade shape and casing geometry on performance and noise are being run in a 5 horsepower test rig.

Computational methods are being developed for propagating modes in ducts based on sound pressure level around the circumference of the duct using cross spectral density and phase-locked methods.

Identification of the sources of noise by acoustic intensity measurements is being conducted on a small reciprocating engine.

ENGINE COOLING SYSTEM PERFORMANCE

A study is being done, in collaboration with Canadian industry and supported by Transport Canada, involving full scale road and wind tunnel tests, to determine the full potential of the cooling fan. Present use of fan and ram air, due to motion, do not represent an optimum from a fuel economy point of view.

AIR CUSHION VEHICLES

An experimental program on the drag and stability of low-speed A.C. rafts over water is in progress. A 1.2 metre model of a typical A.C. ferry is being hovered in a flume in the Hydraulics Laboratory at a range of water speeds, while drag, roll, and pitch are measured, and underwater profiles are photographed. The results correlate well with measurements on ACV HEX-5 towed over water, and with a full-scale ferry.

Construction of the rig for vertical instability experiments is in abeyance while structural alterations to a laboratory test cell are in progress.

Reports on ACV design data and the relation of ACV lift-air requirement relative to terrain have been published.

AUTOMOTIVE FUEL ECONOMY

A report on the effect of traffic signal control strategy on automotive fuel consumption is in preparation. TRANSYT traffic light control program saves time, a small amount of fuel and has fewer stops than the EXISTING control program. Eastbound evening performance with TRANSYT was worse than the EXISTING plan and it may be possible to make improvements in this segment.

NRC–PRATT & WHITNEY HIGHLY LOADED TURBINE

The nozzle ring and turbine section are being installed in the test assembly and connected to pressure readout instrumentation. The pressure and temperature traversing assembly has been connected to a DEC PDP11/34 minicomputer that enables the traversing to be computer-controlled to any number of pre-defined test locations.

ROTOR DYNAMICS

Construction and equipment acquisition has begun on a large rotor dynamics and balancing facility. This facility will accommodate rotors of diameters up to 6 m in length and approximately 2 m in diameter. Installed drive motors have a capacity of 1200 HP. Eventually, the test chamber will be capable of operating at reduced pressures allowing bladed rotors to be tested without serious power dissipation.

The Hooke's couple calibrating device for torsional vibration transducers has recently been overhauled and upgraded.

HYDROSTATIC BEARINGS

This laboratory continues to provide assistance and design service to other potential gas and fluid film bearing users both within NRC and in other government laboratories. In co-operation with three Canadian industrial firms a study is underway to compare the predicted results of computer programs designed to calculate the dynamic performance of self-acting bearings with incompressible lubricants. A recently completed literature survey has provided a broad cross-section of example bearings.

An analytical study is underway to support experimental determinations of the characteristics of air lubricated thrust bearings with one compliant surface.

VIBRATION MONITORING

An experimental rig has been assembled to allow the testing of rolling element bearings to failure. This rig is now being used to compare current methods of vibration detection and their ability to discover incipient faults in rolling element bearings. Because of the nature of fault generation in rolling element bearings the result gathering process is of a rather long-term nature.

A co-operative program with the Defence Research Establishment (Pacific) in Victoria is underway to investigate the combined merits of oil analysis and vibration monitoring as tools for helicopter transmission gear box monitoring.

This laboratory continues to provide specialized vibration measurement and analysis assistance to both industry and government.

FUEL CONTROL SYSTEMS

As the major Canadian manufacturer of fuel control systems for gas turbines in the general aviation market, Aviation Electric Limited of Montréal has developed an advanced concept digital fuel control system that was verified on a computer model of a gas turbine at the NRC. To prove the hardware of the system on a real engine, a co-operative program with AEL will use a Twin-Pac helicopter engine on a dynamometer to enable a steady-state and transient performance assessment to be made.

The Twin-Pac has been installed in No. 2 Test Cell and is in the process of being connected to the cell services to enable preliminary running.

FLIGHT RESEARCH LABORATORY

AIRBORNE MAGNETICS PROGRAM

Experimental and theoretical studies relating to the further development of airborne magnetometer and gradiometer equipment and the application of same to submarine detection and geological survey, are currently in progress. The final report on methods of magnetic aircraft compensation, based on data collected with the North Star aircraft, has been published. A Convair 580 aircraft has been equipped as a multi-purpose flying laboratory for research in aeromagmetic detection and for development of radio and inertial navigation methods. Further modifications may be done to provide a capability for evaluating advanced synthetic aperture radar techniques.

INVESTIGATION OF PROBLEMS ASSOCIATED WITH STOL AND V/STOL AIRCRAFT OPERATIONS

The Laboratory's Airborne V/STOL Simulator is being employed in programs to investigate STOL and V/STOL aircraft flying qualities and terminal area operational problems. Areas of research include a general investigation of flight path control and stability characteristics required to compensate for single engine failure in twin or multi-engine powered-lift aircraft, and the identification of minimum acceptable flying qualities for civil helicopters operating under instrument flight rules.

INVESTIGATION OF ATMOSPHERIC TURBULENCE

A T-33 aircraft, equipped to measure wind gust velocities, air temperature, wind speed, and other parameters of interest in turbulence research, is used for measurements at very low altitude, in clear air above the tropopause, in the neighbourhood of mountain wave activity, and near storms. Records are obtained on magnetic tape to facilitate data analysis. The aircraft also participates in co-operative experiments with other research agencies, in particular, the Summer Cumulus Investigation (see below). A second T-33 aircraft is used in a supporting role for these and other projects.

AIRCRAFT OPERATIONS

The Flight Recorder Playback Centre is engaged in the recovery and analysis of information from the various flight data recorders and cockpit voice recorders used on Canadian military and civil transport aircraft. The military systems are being monitored on a routine basis. Civil aircraft recorders are being replayed to investigate incidents or accidents at the request of the Ministry of Transport. Technical assistance is being provided during incident and accident investigations and relevant aircraft operational problems studied.

INDUSTRIAL ASSISTANCE

Assistance is given to aircraft manufacturers and other companies requiring the use of specialized flight test equipment or techniques.

INVESTIGATION OF SPRAY DROPLET RELEASE FROM AIRCRAFT

Theoretical and experimental studies on spray droplet formation and distribution are carried out. Flight experiments utilize a Harvard aircraft modified to carry external spray tanks. Automatic flying spot droplet and particle analysis equipment is in operation for processing samples obtained in the laboratory and in the field by various agencies. The equipment has potentialities for the analysis of many unusual configurations provided that these may be photographed with sufficient contrast.

AUTOMOBILE CRASH DETECTOR

There is a need for a sensing device to activate automobile passenger restraint systems in incipient crash situations. Investigations are in progress to determine the applicability of C.P.I. technology to this problem.

SUMMER CUMULUS INVESTIGATION

At the request of the Department of the Environment flight studies of Cumulus cloud formations over Quebec and Ontario were instituted during the Summer of 1974. Instrumented T-33 and Twin Otter aircraft with a Beech 18 are being used to determine the properties of Cumulus clouds which extend appreciably above the freezing level. The measurements are being made to assess the feasibility of inducing precipitation over forest fire areas by seeding large cumulus formations. During 1975 a variety of cloud physics instruments were added to the Twin Otter, and special pods for burning silver iodide flares were attached beneath the wing of the T-33 turbulence research aircraft. The effects of seeding on the microstructure of individual cumulus clouds were studied in the Yellowknife area during the summers of 1975 and 1976 and in Thunder Bay in 1977 and 1987. During the summer of 1979 the Twin Otter is participating in similar flight experiments in Montana, jointly arranged by U.S. and Canadian government agencies.

FUELS AND LUBRICANTS LABORATORY

COMBUSTION RESEARCH

Investigation of handling and combustion problems involved in using hydrogen as a fuel for mobile prime movers.

Co-operative studies with Advisory Group for Aerospace Research and Development (AGARD) Working Group 11 to produce a report on aircraft fire safety.

Biogas as an alternate fuel in engine operation.

EXTENSION AND DEVELOPMENT OF LABORATORY EVALUATION

Development of new laboratory procedures for the determination of the load carrying capacity of hypoid gear oils under high speed conditions and under low speed high torque conditions.

Evaluation of filter/coalescer elements for aviation turbine fuels.

Evaluation of longlife filter/coalescer elements from aviation turbine fuel service.

Water separation characteristics of aviation turbine fuels.

PERFORMANCE ASPECTS OF FUELS, OILS, GREASES, AND BRAKE FLUID

Investigation of laboratory methods for predicting flow properties of engine and gear oils under low temperature operating conditions.

Evaluation of static dissipator additives for distillate fuels.

Evaluation of properties of re-refined oils and by-product sludges.

Road test of re-refined automotive oils (co-operation with Environment Canada).

Investigation of the use of anti-icing additive in aviation gasoline.

Investigation of hydrogen content as a means of estimating the combustion characteristics of aviation turbine fuels.

MISCELLANEOUS STUDIES

The preparation and cataloguing of infra-red spectra of compounds related to fuels, lubricants, and associated products.

The application of Atomic Absorption spectroscopy to the determination of metals in petroleum products.

Investigation of the stability of highly compressed fuel gases.

Analytical techniques for analysis of engine exhaust emissions.

Participation in the Canadian (CGSB), American (ASTM) and International (ISO) bodies to develop standards for petroleum products and lubricants.

The design and development of an internal combustion engine/hydraulic transmission hybrid power plant for the energy conserving car.

Further developments of specialized pressure transducers for engine health diagnosis and the development of diagnostic techniques and consultation with licencee in developing production methods for patented transducers.

Evaluation of various products, fuels, lubricants and hardware in respect of their effects upon overall vehicle fuel economy and energy conservation properties.

GAS DYNAMICS LABORATORY

V/STOL PROPULSION SYSTEMS

A general study of V/STOL propulsion system methods with particular reference to requirements of economy and safety.

INTERNAL AERODYNAMICS OF DUCTS, DIFFUSERS AND NOZZLES

An experimental study of the internal aerodynamics of ducts, bends, diffusers and nozzles with particular reference to the effect of entry flow distortion is geometries involving changes of cross-sectional area, shape, and axial direction.

SHOCK PRODUCED PLASMA STUDIES

A general theoretical and experimental investigation of the production of high temperature plasma by means of shock waves generated by electromagnetic and gas dynamic means, and the development of diagnostic techniques suitable for a variety of shock geometries and the study of physical properties of such plasmas.

NON-DESTRUCTIVE SURFACE FLAW DETECTION IN HOT STEEL BILLETS

A flaw detection system for metal bars is being tested. Eight inductive bridge circuits, spaced around the bar and sequentially sampled, detect the flaw through a change in coil inductance. The system lends itself to easy elimination of stand-off and eccentricity errors and is currently being adapted to industrial use. Interpretation of test results via microprocessors is in hand. A rugged, heat-resistant circuit is being designed for in-plant application.

HIGH PRESSURE LIQUID JETS

High speed water jets generated by pressures in the range of 1000 to 60,000 psi can be used for cutting a wide variety of materials, e.g. paper, lumber, plastics, meat, leather, rock, etc., and for cleaning surfaces such as masonry, tubular heat exchangers, etc. Nozzle sizes, depending on the application, are in the range from 0.002 to 0.15 in. diameter. A technique for manufacturing small nozzles in the range 0.002 to 0.015 has been developed using standard sapphire jewels available from industry. Larger orifices are manufactured and polished using standard shop procedures.

At present, the following investigations are active in the laboratory:

1. Drilling of rocks of various types, including granite, using a high pressure rotating seal and single and dual orifice nozzles specially developed for this purpose.

2. Study of the effects produced by cavitating jets, how best to produce them and where they may be usefully applied.

3. Collaborative experimental work, in collaboration with the Low Temperature Laboratory, on the breaking and cutting of ice.

HEAT TRANSFER STUDIES

An investigation of methods of increasing boiling and condensing heat transfer coefficients by treatment of the heat transfer surface is in progress.

A co-operative project with the Division of Building Research will determine the usefulness of the thermosiphon as a ground heat source for a heat pump.

Experiments continue on the use of steam as a heating method for soldering tubing to thin sheet, as in flat plate solar collectors.

An inexpensive, leakproof heat exchanger has been developed for use in solar energy systems. Fabrication is simple and it is suitable for production in small batches.

Work has started on a new type of temperature control thermosiphon. Previous types have been designed to control the temperature of a heat source; this design controls the temperature of a heat sink.

COMPUTATIONAL FLUID DYNAMICS

Numerical simulations are carried out in connection with projects initiated internally or as collaborations with outside organizations. At present the field of greatest interest concerns the problems of absorption of laser energy by plasmas and four topics are currently being pursued:

1. A study of the mechanism of re-entry waves occurring when beam intensity is reduced below the level at which laser-supported detonation can exist.
2. Absorption of laser energy by hydrogen plasma confined by a magnetic field (laser heated solenoid).
3. A study of the fluid mechanics accompanying continuous discharge of laser energy into a spot fixed in space.
4. Laser-initiation of a high-density Z-pinch.

GAS TURBINE BLADING STUDIES

A program on the theoretical and experimental study of the performance of highly loaded gas turbine blading has been undertaken as a collaborative program with industry and universities.

INDUSTRIAL PROCESS, APPARATUS, AND INSTRUMENTATION

There is an appreciable effort, on a continuing basis, directed towards industrial assistance. This work is of an extremely varied nature and, in general, requires the special facilities and capabilities available in the laboratory.

Current and recent co-operative projects with manufacturers and users include:

(a) Flow problems associated with industrial gas turbine exhaust systems (Foster Wheeler).
(b) Combustion studies for industrial gas turbine applications (Westinghouse and Rolls-Royce).
(c) Application of thermosiphon as an energy conserving device in industrial applications (Dept. of Agriculture, Ministry of Transport, Farinon Electric, Chromalox Canada Ltd).
(d) Scaled model studies on steel and copper converters to establish relative performance and ceramic liner deterioration rates (Canadian Liquid Air and Noranda).
(e) High pressure water jet applications in industry (High Pressure Systems Ltd.).
(f) Scaled model studies to establish the performance of complex industrial flue systems with a view to establishing specific design and performance criteria. (Noranda and Inco Canada Ltd.).
(g) Model studies of internal flows in reactor hood and waste heat boiler (Noranda and Kennecott Copper Corp.).
(h) Altitude test chamber for small gas turbines (Pratt & Whitney Aircraft of Canada Ltd.).
(i) Experimental study of a novel fan design (Rolls-Royce).

HIGH SPEED AERODYNAMICS LABORATORY

CALIBRATION OF THE SUBSONIC AND TRANSONIC TEST SECTIONS OF THE 5-FT. X 5-FT. BLOWDOWN WIND TUNNEL

In addition to the calibration measurements and results reported in QB 1979(1), further measurements have been made in the transonic and subsonic test sections to assess the flow quality.

These were effected with an instrumented cone, loaned by N.L.R., Amsterdam. The cone was equipped with 14 responsive Kulite pressure transducers mounted at intervals of 15 and 25 mm along 340 mm of the cone surface. One side of each transducer was closely connected to the surface and able to respond to pressure fluctuations in the boundary layer up to nearly 10 kHz.

For the transonic test section, in the range $0.5 \leq M \leq 1.2$, the foremost transducer indicated a noise level that, in terms of C_p rms, varied with M from about 0.75% at M = 0.5, rising to 1.3% at M = 0.7 and falling to 0.6% at M = 1.2. A slight Reynolds number effect was noted, the tendency being for C_p rms to increase by 0.1 to 0.2% as the unit Reynolds number increased from 16×10^6 to 26×10^6 per metre.

The subsonic test section exhibited the highest noise at M= 0.3 (1.2%) but increasing Mach numbers reduced the value to little more than 0.5% for $0.5 \leq M \leq 0.8$. The Reynolds number influence was very small for this test section.

CALIBRATION OF TRANSONIC SECTION IN HALF-MODEL GEOMETRY

Calibration of the empty transonic 5-ft. x 5-ft. section in half-model geometry is completed. Static pressure measurements along the ceiling, floor and reflection plate were made at three stagnation pressures in the Mach number range $0.3 < M < 0.99$. Preliminary results indicate that in the region extending 10 inches forward and aft of the balance centre there is little or no Mach number gradient and little or no difference between the static pressures measured in the plenum chamber and in the working section.

DATA SYSTEM IMPROVEMENTS ON 5-FT. X 5-FT. WIND TUNNEL

Modernizing and upgrading of the data system on the 5-ft. tunnel is now in the final stages and will be installed over the summer months.

A total of up to 96 analog channels (48 high quality and 48 lower quality) will be available, with switch selected gains of 1 to 5000 and front end filters of 3 Hz to 10 kHz. "Status" channels will be digitized at source and packed to minimize data volumes.

Data conversion throughputs have been demonstrated at 40 kHz average, with bursts of 100 kHz rates through 2 15-bit A/D converters simultaneously.

Real-time tunnel control, model attitude and data acquisition tasks will be performed in the same processor through software, utilizing tables prepared in advance to define the various operations required.

Progress toward on-line data reduction is proceeding.

TRANSONIC EQUIVALENCE RULE INVOLVING LIFT

The classical area rule is well known and its application to wing-body design and drag reduction is demonstrated on many existing aircraft. Recent advances in transonic aerodynamic theory show that the classical area rule requires a modification to account for lift. A series of experiments is being prepared in order to investigate these new concepts. The results of these experimental studies will provide criteria for wing-body design with emphasis on drag reduction for aircraft cruising at transonic speeds.

TWO-DIMENSIONAL TRANSONIC FLOW STUDIES

The small disturbance transonic computer program, developed for free air isolated airfoils, is being rewritten for use in computing flow about cascades. Such a program will be useful for analyzing compressor configurations.

STUDIES OF WING BUFFETING

A theoretical study of the transient response of a wing to non-stationary buffet loads is in progress. Various forms of the power spectral density of the aerodynamic loading on the wing have been considered for a number of load versus time history during buffet manoeuvres. A wind tunnel investigation of the surface pressure and normal force fluctuations associated with buffeting has been carried out on the BGK No. 1 airfoil.

REYNOLDS NUMBER EFFECTS ON TWO-DIMENSIONAL AEROFOILS WITH MECHANICAL HIGH LIFT DEVICES

Under a joint NRC/de Havilland enterprise administered under the PILP program and extensive set of low speed aerodynamic measurements were made in the 2-D insert in the period September 26 – November 30, 1978, on a multi-component aerofoil model.

During the first phase of the work several trailing-edge flap geometries (with and without a leading-edge slat) were optimized at a chord Reynolds number of 6×10^6; subsequently their performance at lower and high Reynolds numbers were checked.

In a second phase of tests with this aerofoil some boundary layer measurements were made near the trailing-edge of the main element, utilizing a new boundary-layer traversing rig. These latter measurements were primarily directed at checkout of the traversing rig in its simplest form, with the objective of developing reliable gear for more extensive boundary layer measurements on high lift multi-component aerofoils in the near future.

Work on an iterative solution of the compressible boundary layer flows about multi-element airfoil is continuing at the University of Manitoba.

HOLE ERROR INVESTIGATION

An experimental study has been completed, in collaboration with Professor J.C. Menneron, of the University of Sherbrooke, of the effect of orifice size on the measurement of pressure on the surface of an aerofoil at subsonic free-stream velocities. Speeds up to $M = 0.7$ and chord Reynolds number from 6×10^6 to 33×10^6 were used. Orifice diameters range from 0.006 in. to 0.016 in. Analysis of the data clearly indicates that the value of the chordwise force coefficient, obtained by integration of the surface pressure, consistently increases with the size of the orifice. The effect is rather more pronounced at $M = 0.5$ and 0.7 than at $M = 0.3$.

5-FT. X 5-FT. WIND TUNNEL TESTS

The effects of various leading edge droop geometry have been investigated, using the PT1:m3 half-model. The tests were performed in the Mach number range $0.5 < M < 0.95$ at chord Reynolds number 15×10^6. The test results will be published in NAE LTR-HA-5X5/0124.

Manufacturing of a half-model fuselage to be tested in conjunction with the T:m12 and PT10:m5 wings has been completed.

TESTS FOR OUTSIDE ORGANIZATIONS

Saab-Scania

Tests were conducted at transonic speeds on a complete aircraft model to compare the results form two geometrically similar balances. These balances had produced widely differing results when used in a similar model at another testing facility.

A 1/10th scale half-model has been tested to determine the static stability characteristics, drag and buffet onset boundaries and buffet magnitude.

FFA

A 1/10th scale half-model has been tested for FFA to determine the static stability characteristics and drag in the Mach number range $0.5 < M < 0.99$.

HYDRAULICS LABORATORY

ST. LAWRENCE SHIP CHANNEL

Under the sponsorship of the Ministry of Transport, a study to improve navigation along the St. Lawrence River, using hydraulic and numerical modeling techniques.

NUMERICAL SIMULATION OF RIVER AND ESTUARY SYSTEMS

Mathematical models have been developed to simulate tidal propagation in estuaries, wave refraction in shallow water and littoral drift processes. The feasibility of using array processors to solve the hydrodynamic equations is presently under study.

WAVE FORCES ON OFF-SHORE STRUCTURES

Wave flume study to determine design criteria for off-shore structures, such as cooling water intakes or outfalls, mooring dolphins, drilling rigs, etc.

RANDOM WAVE GENERATION

A study of random waves generated in a laboratory wave flume by signals from a computer. Special attention is paid to the simulation of wave groups.

STABILITY OF RUBBLE MOUND BREAKWATERS

A flume study for the Department of Public Works to determine stability coefficients of armour units and the effect of a number of wave parameters on the stability of rubble mound breakwaters, including the effect of wave grouping.

WAVE LOADS ON CAISSON TYPE BREAKWATERS

A flume study for the Department of Public Works to determine the overall loading, as well as the pressure distribution on various Caisson-type breakwaters.

WAVE POWER AS AN ENERGY SOURCE

A general study to assess the wave power available around Canada's coast and to evaluate various proposed schemes to extract this energy. International co-operation is taking place through the International Energy Agency of OECD.

MOTIONS OF LARGE FLOATING STRUCTURES, MOORED IN SHALLOW WATER

A mathematical and hydraulic modeling program will be carried out to develop techniques and methods to forecast motions of, and mooring forces on large structures moored in shallow water.

CALIBRATION OF FLOW MEASURING DEVICES

Facilities to calibrate various types of low meters up to a maximum capacity of 5,000 gpm are regularly used for/or by private industry and other government departments.

OSHAWA HARBOUR MODEL STUDY

A hydraulic model study for Public Works, Canada of Oshawa Harbour on Lake Ontario, to investigate changes in the layout of the present breakwaters to reduce the level of wave agitation inside the harbour basin.

TRANSPORT OF SAND ON BEACHES

A method has been developed for calculating rates of sand transport in the presence of waves, a modification of the Ackers and White method for river flows. A new flume was recently constructed in which the method can be tested.

LOW HEAD WATER TURBINES

A research program has been started to investigate the feasibility of extracting power from water currents, by using low head turbines.

HYBRID MODELING TECHNIQUES USING ARRAY PROCESSORS

Estuaries where tidal power can be developed require the use of large physical models of the area. The laboratory has demonstrated that a "hybrid model" can dynamically couple together a mathematical model to the physical model at the boundaries, therefore the physical model need not be very large in extent. An array processor will be used to realize the mathematical portion of the hybrid model.

LOW SPEED AERODYNAMICS LABORATORY

WIND TUNNEL OPERATIONS

The three major wind tunnels of the laboratory are: the 15-ft. diameter open jet vertical tunnel, the 6-ft. × 9-ft. closed jet horizontal tunnel, and the 30-ft. V/STOL tunnel. During the quarter, a number of test programs were carried out for groups both within and outside of the government. Within the government, test programs included studies on building aerodynamics and ship-hull flow visualization. Studies for non-government groups included the aerodynamics of a road vehicle, an aircraft, a building, a vertical-axis wind turbine, an aircraft insecticide spray-boom system and downhill skiers.

Work continues on the contract for the new data acquisition, reduction and control system for the 6-ft. × 9-ft. wind tunnel. Final installation at the site will take place in April 1979.

WIND ENGINEERING

In collaboration with the Division of Building Research, an aerodynamic investigation of Commerce Court, Toronto is being undertaken. The purpose is to obtain wind tunnel comparisons with full-scale measurements of surface pressures and building movements. Wind tunnel tests have been completed in which surface pressures were measured and are continuing on an aeroelastic model.

A series of six 1:10 scale truck models are being designed and constructed to continue NRC's program in truck energy conservation through aerodynamic drag reduction and in support of a joint NRC/Transport Canada – DOT/SAE (U.S.A.) wind tunnel testing program.

Measurements of wind properties are being continued on the Lions' Gate Bridge, Vancouver as part of an aerodynamic investigation of the bridge. Outputs from five anemometers and two accelerometers that measure bridge motion are recorded by an automated system. Site assistance is being provided by Buckland and Taylor Limited, Vancouver.

Wind measurements are continuing at the site of an ore conveyer bridge crossing the Similkameen river valley in British Columbia. The proposed conveyer bridge was wind tunnel tested at NAE in Dec. 1978 and Jan. 1979 for Buckland and Taylor Ltd.

A study of street level winds in the downtown core of the City of Ottawa is underway. The first phase will establish a probability distribution of the existing wind climate and the second phase will be the simulation of the wind conditions using a 1:400 scale model in the NAE 30-ft. × 30-ft. wind tunnel. The study is jointly sponsored by the City of Ottawa, the Department of Public Works, the National Capital Commission and the National Aeronautical Establishment. A contract for the construction of remote wind sensing units has been let and a PDP 11/03 micro system has been received. Work has begun on constructing the model. The first series of wind tunnel tests will take place in September 1979.

Development work on a ravel surface mounted device for measuring street level winds on city model was carried out in the 3-ft. × 3-ft. wind tunnel. The device connects to a pressure transducer and scanivalve and allows street level winds to be measured rapidly at a large number of locations.

Models of three home type microwave antennas at 1:12 scale were wind tunnel tested in the 6-ft. × 9-ft. wind tunnel to determine wind loads for Andrew Antenna Co.

Experimental work on the effect of turbulence on the flutter instability of a 1:110 scale bridge sectional model was started in the 3-ft. × 3-ft. wind tunnel.

FLUIDICS

Co-operative studies with D.G. Instruments of a 3-axis velocity sensor are continuing using both NRC and industry developed concepts. Studies of vortex excitation of velocity sensor probes have been carried out in co-operation with Fluidynamics Devices Ltd. A program of applications of laminar flow in thin passages is being carried out in co-operation with the Control Systems and Human Engineering Laboratory of DME.

VERTICAL AXIS WIND TURBINE

In July 78, the rotor of the 230-kW demonstration wind turbine on the Magdalen Islands collapsed while the drive train was undergoing maintenance. An investigation of the causes of the accident uncovered no basic flaw in its design or construction. Therefore, it was decided to rebuild it. The new rotor is scheduled to be installed in August. Two 50-kW plants were installed and directly connected to local power networks in Newfoundland and Saskatchewan.

LOW TEMPERATURE LABORATORY

THERMAL PROTECTION OF TRACK SWITCHES

The use of heat to eliminate switch failures from snow and ice is a standard approach to this problem. Work has been carried out on improving the efficiency of forced convection combustion heaters and the means of distributing heat to the critical areas of a switch.

HORIZONTAL AIR CURTAIN SWITCH PROTECTOR

A non-thermal method of protecting a switch from failure due to snow has been undergoing development and evaluation. This method consists of high velocity horizontal air curtains designed to prevent the deposit of snow in critical areas of a switch. The tests conducted to date are especially encouraging with respect to yards and terminals. Additional evaluation is required for the line service application.

NEW RAILWAY SWITCH DEVELOPMENT

The ultimate solution to the existing problem of snow and ice failure of the point switch would appear to be replacement by a new design that is not subject to failure in this way. A switch has been designed, fabricated, laboratory tested and has now completed one winter season of field trials. The design involves only shear loading from snow and ice.

MISCELLANEOUS ICING INVESTIGATIONS

Analytical and experimental investigations of a non-routine nature, and the investigation of certain aspects of icing simulation and measurement.

TRAWLER ICING

In collaboration with Department of Transport, an investigation of the icing of fishing trawlers and other vessels under conditions of freezing sea spray, and of methods of combatting the problem.

AIRBORNE SNOW CONCENTRATION

To provide statistical data on the airborne mass concentration of falling snow in order to define suitable design and qualification criteria for flight through snow, measurements of concentration and related meteorological parameters are being made.

SEA ICE DYNAMICS

Analytical and experimental work on the techniques of forming low-strength ice from saline solutions is being carried out in connection with proposed modeling studies of icebreaking ships and arctic port facilities.

An investigation is being made into the modeling of sea ice based on the freezing of aqueous solutions. The objective of the investigation is to improve the dynamic similarity in model testing in simulated sea ice.

LOCOMOTIVE TRACTION MOTORS

An investigation into the failure of locomotive traction motor support bearings due to winter service has been undertaken. The presence of moisture either as water or ice in the oil reservoirs is suspected to be a contributing cause of the failures.

HIGH PRESSURE CUTTING OF ICE

Experimental work is being carried out in collaboration with Gas Dynamics personnel on the cutting of ice with high pressure water jets. One phase of this work has been concerned with the removal of ice from a substrate such as concrete. The other work on ice cutting has been for possible application to ice breaking ships.

MARINE DYNAMICS AND SHIP LABORATORY

HIGH SPEED CRAFT

Model tests in calm water and in waves have been completed on ten models from a systematic series and results are being evaluated. The series is being extended by the construction of an additional six models.

COMBINATION FISHING VESSEL

Model tests carried out last year on a new design of 70 ft. West Coast combination salmon and herring fishing vessel are being extended in order to define more comprehensively its safety against capsize in waves. Parameters under investigation are ship displacement, initial stability condition, wave height, wavelength, ship speed and relative wave direction.

These additional experiments, being carried out in the 130 m. × 65 m. × 3.5 m. seakeeping and manoeuvring basin using a radio-controlled free-running model, are in support of a current move internationally to place the subject of vessel capsize on a more scientific footing.

65 FT. EAST COAST FISHING VESSEL

The laboratory is currently investigating whether increase in the beam of small fishing vessels, which has advantages for deck working, leads to any deterioration in seakeeping qualities.

Beam wave rolling experiments have indicated that the use of passive anti-rolling tank stabilization is not altogether suitable for this class of vessel. Conventional bilge keels suffer from ice damage so the possible use and effectiveness of bottom keels is being investigated.

SWATH MANOEUVRING INVESTIGATION

An investigation into the effect of rudder position on the manoeuvrability of a Small Waterplane Area Twin Hull (SWATH) vessel is being carried out using a radio-controlled free running model in the laboratory's large manoeuvring basin.

LOCK MODEL STUDY – EXTENSION

The second series of model tests for the St. Lawrence Seaway Authority into the effect of vessel size and lock geometry on lock transit times in the Welland Canal has been analysed and reported. These studies are in direct support of a prototype marine shunter trials program currently being carried out by the Seaway Authority.

CABLE FAIRINGS

Comparative tests with cable fairings are being carried out in the laboratory in an effort to develop low drag stable sections, for Canadian Industry and other Government Departments.

M.V. "ARCTIC"

Dedicated ice trials aboard the M.V. Arctic are planned for this fall. The laboratory's involvement is to monitor these trials and analyse the results. The M.V. Arctic is Canada's first icebreaking bulk cargo vessel and has been built to meet the Arctic Waters Pollution Prevention Regulations as a Class 2 ship. The laboratory has advised in the design and installation of a sophisticated data system with which the vessel has been equipped to measure ice loadings, using 160 strain gauges mounted on the hull, as well as ship motions and propulsion parameters. The data from these trials should be extremely valuable for the design of future Arctic bulk carriers.

RAILWAY LABORATORY

YARD EXPERIMENTS

At the request of Bombardier Inc., their LRC (Light-Rapid-Comfortable) rail coach has been instrumented and given an 800,000 lbs compression test in accordance with AMTRAK's requirements. This aluminum coach, completely designed and built in Canada, passed the test and the results from over 100 strain gauges have been analyzed and a report is being written.

At the request of the Department of National Defence, impact tests to simulate classification yard conditions have been conducted to evaluate various methods of securing armoured personnel carriers to a flat car. Results are being analyzed and a report is being prepared.

In the area of track force measurement, instrumentation has been loaned and advice given to the Canadair group in charge of setting up a light rail vehicle test track in Kingston.

LABORATORY FACILITIES FOR RAILWAY RESEARCH

Lighting and power outlets for the new squeeze frame cover building (U-90) have been installed. High pressure oil lines for the rail car shaker and the track simulator have been designed, and the material for same has been ordered.

The use of solar energy for heating, cooling and water heating for Buildings U-89 and U-90 is under investigation.

Work continues on fitting of insulation and inside panels in the working section of Instrument Car 62.

Work on the NRC curved track simulator continues in the Manufacturing Technology Centre with the testing of the differential drive gear units and the design of the curve control position levers.

In collaboration with the Analysis Laboratory, work continues on a mathematical model of the curved track simulator. In particular, the wheel-roller interaction phenomenon is being studied.

Studies are being conducted on the consequences to a rail axle set of independently rotating wheels with regard to stability and curving.

GENERAL INSTRUMENTATION

The Laboratory, in co-operation with the Marine Dynamics and Ship Laboratory, have built a micro-processor based ship's motion analyzer. Development of the digital programs for computation and control, including laboratory checks of the instrument, using field data, are presently being carried out by the Marine Dynamics and Ship Laboratory.

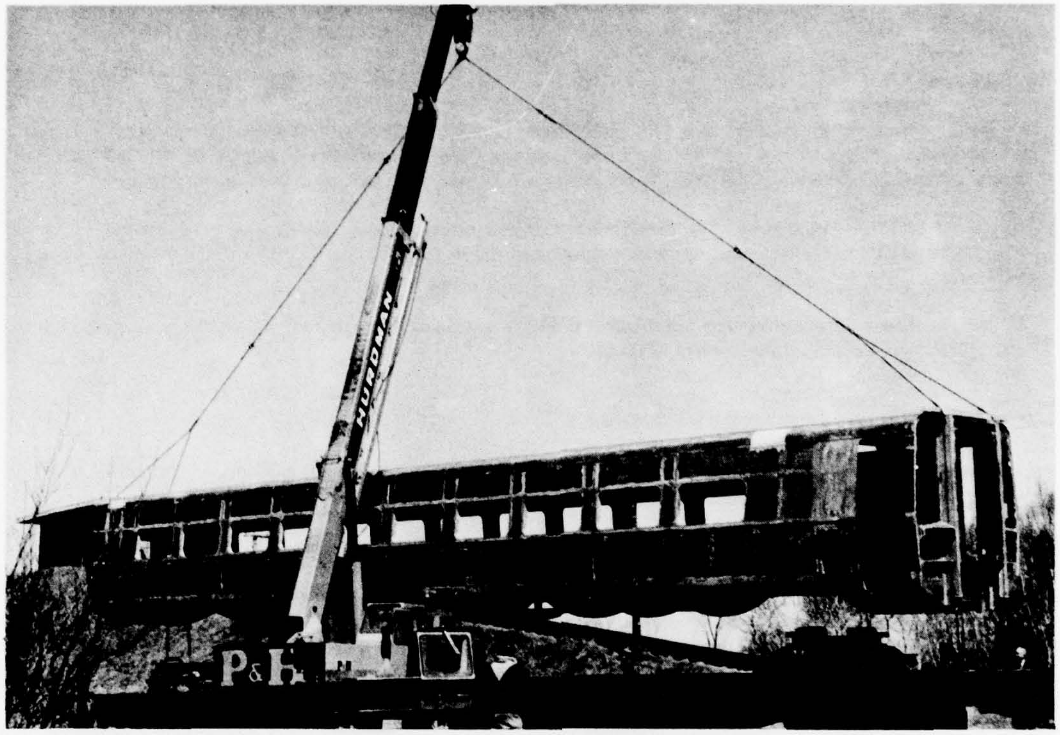
A non-contacting transducer is being developed to measure speed and displacement of ferro-magnetic surfaces by correlating two magnetic noise signals.

An instrumented locomotive wheelset for measuring vertical and lateral rail/wheel forces in service is being developed for Transport Canada Research and Development Centre. Strain gauging, wiring, and calibration of the vertical and lateral force bridges on each wheel have been completed. Spin tests and check out of the telemetry is under way.

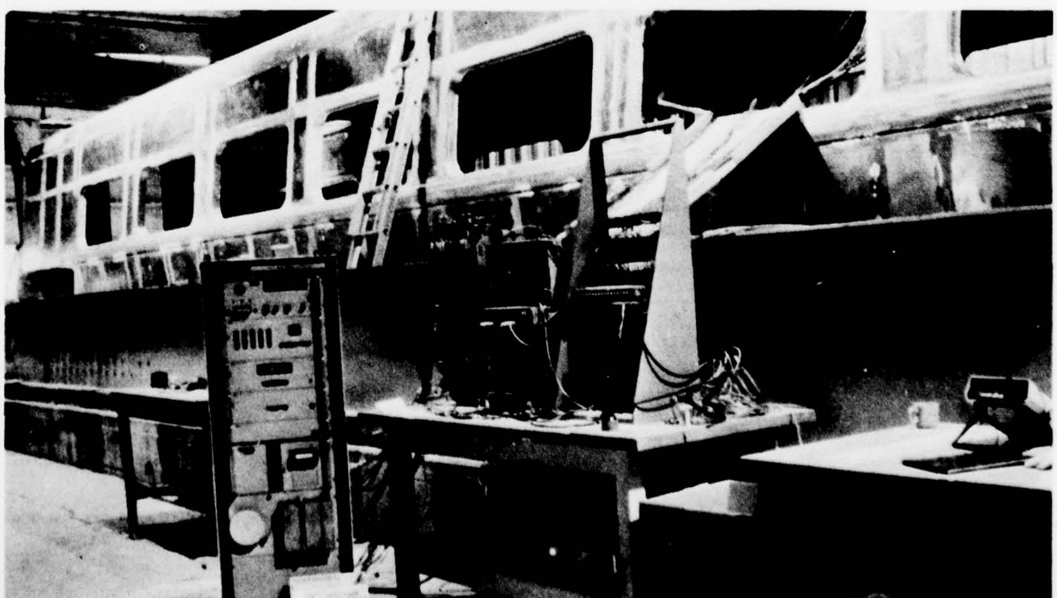
A commercial desktop calculator-computer with CRT display, high speed printer, and plotter have been added to our fast fourier transform set up to further enhance our data processing capabilities.

TECHNICAL PHOTOGRAPHY

Besides services to the Mechanical Engineering Division Laboratories, assistance was given to the National Aeronautical Establishment's research section using stills and high speed movies.



UNLOADING OF THE LRC CAR PRIOR TO THE SQUEEZE TEST



LRC CAR DURING SQUEEZE TEST IN BLDG. U-90

A DATA ACQUISITION SYSTEM WAS USED TO RECORD STRAIN IN OVER 100 STRATEGIC POINTS ON THE ALUMINUM CAR BODY

RAILWAY LABORATORY

DIVISION OF MECHANICAL ENGINEERING

STRUCTURES AND MATERIALS LABORATORY

MOTOR VEHICLE SAFETY

In collaboration with the Road and Motor Vehicle Traffic Safety Branch of Transport Canada the second phase of the studies evaluating headlamp performance is underway. Attention is focussed on the determination of population characteristics of headlamps presently in use. Mean illuminance and glare quandrant values together with data describing the influence of dirt, aim and voltage for a large sample of vehicles are being analyzed within the previously defined system's concept.

VIDEO PHOTOGRAMMETRY SYSTEM FOR REAL TIME THREE-DIMENSIONAL CONTROL

Potential applications for an NRC/NAE 30 Hz Video Photogrammetry System developed for three-dimensional machine control tasks are being examined. The system is based on the principle that knowledge of the centroid data for four targets on a rigid body permits the single camera photogrammetric solution to be solved for each video frame to determine the position and orientation of the body, in real time, for three-dimensional machine control. Initial applications will focus on remote manipulator systems.

METALLIC MATERIALS

Structure-property relationships in aerospace alloys, including cast or wrought nickel and cobalt-base superalloys, high strength titanium and aluminum alloys. Studies on the consolidation and TMT processing of titanium and superalloy compacts by hot isostatic pressing, isothermal and superplastic forging, and extrusion. Studies on the mechanical properties of these materials. The mechanics of cold isostatic compaction of metal powders, and properties of hydrostatically extruded materials. Studies of the oxidation/hot corrosion behaviour of coated and uncoated refractory metals and superalloys.

FRACTOGRAPHY AND FAILURE ANALYSIS

Utilization of transmission and scanning electron microscopes in the study of fracture surfaces, leading to the identification of the micromechanisms of fracture involved in the failure of structural components. From such information it is frequently possible to determine the causes of failures and to suggest remedial action.

FATIGUE OF METALS

Studies of the basic fatigue characteristics of materials under constant and variable amplitude loading; fatigue tests on components to obtain basic design data; fatigue tests on components for validation of design; studies of the statistics of fatigue failures; development of techniques to simulate service fatigue loading.

OPERATIONAL LOADS AND LIFE OF AIRCRAFT STRUCTURES

Instrumentation of aircraft for the measurement of flight loads and accelerations; fatigue life monitoring and analysis of load and acceleration spectra; full-scale fatigue testing of airframes and components. Non-destructive testing and damage tolerance evaluation.

THEORY OF STRUCTURES

Studies of the application of finite element methods to structural problems. Assessment of commercially available computer programs for structural analysis. Calculation of stress-intensity factors for cracked three-dimensional bodies. Damage tolerance analysis.

AEROACOUSTICS

Studies of aerospace-related acoustical problems with special reference to intense noise and its effect on structures. Evaluation of aerospace hardware in intense noise. Studies of jet exhaust noise, wind-tunnel noise, techniques for digital signal processing, enhancement of signals obscured by noise.

FLIGHT IMPACT SIMULATOR

Simulator developed and calibrated to capability of accelerating a 4-lb. mass to a velocity of 1000 ft./sec., and an 8-lb. mass to a velocity of 760 ft./sec. Available to Canadian and Foreign manufacturers for certification of aircraft components and structures. Also used for fundamental studies of the impact process and evaluation of transparencies.

CALIBRATION OF FORCE AND VIBRATION MEASURING DEVICES

Facilities available for the calibration of government, university, and industrial equipment include deadweight force standards up to 100,000 lb., dynamic calibration of vibration pick-ups in the frequency range 10 Hz to 2000 Hz.

NON-METALLIC COMPOSITE MATERIALS

Studies of non-metallic composites including resins, cross-linking compounds, polymerization initiators, selection of matrices and reinforcements, application and fabrication procedures, material properties, and structural design.

POLICE EQUIPMENT STANDARDS

The NRC/CACP Technical Liaison Committee on Police Equipment is a bilateral arrangement for bringing together police and government personnel to review police equipment requirements, equipment performance specifications, and conformance testing procedures. Work of the Committee is expedited by a permanent Secretariat which has a primary responsibility for continuity in the activities of a number of Sections, each dealing with a particular area of expertise, and for co-ordinating work and specialist contributions from various participating Departments and organizations.

AD-A074 885   NATIONAL RESEARCH COUNCIL OF CANADA OTTAWA (ONTARIO) --ETC   F/G 1/3
QUARTERLY BULLETIN OF THE DIVISION OF MECHANICAL ENGINEERING AN--ETC(U)
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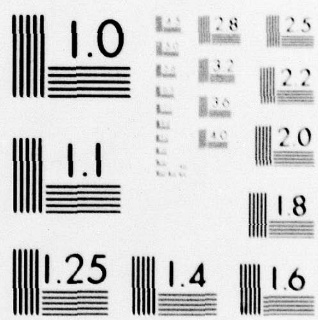

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

UNSTEADY AERODYNAMICS LABORATORY

DYNAMIC STABILITY OF AIRCRAFT

Measurement of direct, cross and cross-coupling stability derivatives due to roll oscillation.

Development of a translational-oscillation apparatus.

Vertical acceleration experiments.

Measurements of cross-coupling derivatives at high angles of attack.

Development of hydraulic drive systems for high-load oscillatory apparatuses.

Development and construction of new, fully-digital instrumentation system for dynamic experiments.

ATMOSPHERIC DISTRIBUTION OF POLLUTANTS

Instrumentation of a small mobile laboratory to measure airborne particulates and of an aircraft to detect atmospheric tracers.

Analysis of the downwind vertical spread and turbulent deposition of gaseous and aerosol pollutants from sources near the ground, with special emphasis on the effect of droplet evaporation.

Determination of long-distance drift of tracer chemical from a discrete spray, in New Brunswick.

TRACE VAPOUR DETECTION

Development of highly sensitive gas chromatographic techniques for detection of trace quantities of vapours of pesticides, explosives and fluorocarbons.

Sensitivity evaluation of commercially available explosive detectors.

Development of stopped-flow and continuous-flow vapour concentrators.

Testing of biosensors.

Development and construction of a portable explosives vapour detector.

WORK FOR OUTSIDE ORGANIZATIONS

Damping and cross-coupling experiments for NASA.

Feasibility and design studies for NASA.

Aircraft-security feasiblity studies and development projects for Transport Canada.

Feasibility studies for DSMA, Toronto.

Experimental assistance to RCMP.

Field experiments in New Brunswick for Forest Protection Ltd., Fredericton.

WESTERN LABORATORY (VANCOUVER)

PRACTICAL FRICTION AND WEAR STUDIES

Laboratory simulations of practical tribological systems to study friction, wear and lubrication behaviour of lubricants and bearing materials in response to specific external requests. For example, studies of methanol lubricity and wear in fuel pump gears with methanol as the working fluid are in progress.

FUNDAMENTAL STUDIES IN TRIBOLOGY

A special rolling contact apparatus is being built that will allow experimental studies of rail and wheel wear, and lubrication to be made in the laboratory.

LUBRICANTS

Mechanical testing of both solid and liquid lubricants has been carried out at the request of local industry and utility organizations.

In co-operation with F & L Laboratory a program has been initiated to monitor, by ferrographic methods, wear debris accumulated in used automotive engine oils. This is part of an Environment Canada project to assess the efficacy of re-refined oils for automotive use.

BEARINGS

The laboratory study of the wick lubrication system of locomotive traction motor bearings is continuing.

INSTRUMENTATION

Work is continuing on the instrumentation and control system for the rail-wheel wear test rig now nearing completion.

An analogue/digital divider circuit has been designed and built to compute friction coefficients for the 'pin-on-disc' wear tester in the tribology laboratory.

A computerized optical density measuring system for use as a microscope attachment for assessing relative wear particle concentrations in lubricants has been designed, built and installed in the tribology laboratory.

NUMERICALLY CONTROLLED MACHINING

Technical assistance on this subject is being provided to firms and other institutions in Western Canada which are considering the purchase of numerically controlled machines to improve their production efficiency. Seminars are held to explain the fundamentals of numerical control and programming.

Use is being made of computer-assisted programming and punched-tape preparation as a means of reducing manual programming time for items requiring a large number of geometrical statements. Seminars are held to demonstrate the principles and features of this method of NC part programming. This technique is being used to assist new users of NC equipment to get their equipment quickly into production.

A preliminary design and feasibility study has been completed of an NC machine to cut the wooden plugs for the manufacture of moulds for fibreglass boats up to 80 ft. long. Also the design of a low cost NC machine for the wood cabinet making industry is being examined.

APPROPRIATE TECHNOLOGY

The laboratory has recently been monitoring the progress of this new technological movement towards smaller scale, environmentally and socially appropriate decentralized industrial development. The laboratory has been examining the technical aspects of a number of possible small scale processes, e.g. paper cutting equipment, and welcomed other proposals for co-operative projects in this area.

LOW TEMPERATURE TEST FACILITY

The low temperature ($-45^{\circ}C$) test chamber has been used by a manufacturer of cable TV equipment to test line amplifiers at low temperatures.

PUBLICATIONS

National Aeronautical Establishment

LR-597 THEORETICAL ANALYSIS OF THE TRANSIENT RESPONSE TO NON-STATIONARY BUFFETS LOADS.

Lee, B.H.K., National Aeronautical Establishment, April 1979.

A method for predicting the response of a wing to non-stationary buffet loads is presented. The wing is treated as a cantiliever beam with known mass distribution. Using generalized co-ordinates, the vibration of the wing is governed by the second order mass-spring-damper oscillator equation. The buffet load on the wing is expressed as an integral of the sectional force, which is a function of the spanwise location and time. The non-stationary load is represented as the product of a deterministic time function multiplied by a statistically stationary random function. The time history of the applied load is segmented into a number of time intervals. Analytical expressions for the mean square response of the wing displacement are derived using a power spectral density for the random part of the applied load, similar to that used in the theory of isotropic turbulence. The effects of damping, ratio of the undamped natural frequency of the system to the half power frequency of the power spectral density, length of time segment, and duration of applied load on the response of the wing have been investigated for three examples of the load versus time histories.

LR-598 A PERTURBATION THEORY OF TWO-DIMENSIONAL TRANSONIC WIND TUNNEL WALL INTERFERENCE.

Chan, Y.Y., National Aeronautical Establishment, April 1979.

The wind tunnel wall interference in transonic speed is formulated as a perturbation to the basic flow around the airfoil in free air. The perturbation equation is derived from the transonic small disturbance equation and is linear but with variable coefficients containing the non-linear solution of the basic flow. The equation is solved numerically by a direct matrix method using the classical boundary condition for a porous wall. The solution in terms of lift versus angle of attack agrees well with that calculated directly from the small disturbance equation.

Division of Mechanical Engineering

ME-245 OVERLAND AND AMPHIBIOUS ACV DESIGN DATA RELATING TO PERFORMANCE.

Fowler, H.S., Division of Mechanical Engineering, April 1979.

This handbook of data endeavours to collect and present in practical form such design data relating to performance as are currently publicly available.

The art is at present in an early stage of its development, and many of the data given are tentative or incomplete, and are hedged around by ill-defined boundary conditions.

We shall attempt to keep up with the ever-shifting frontiers of ignorance by issuing amendments to this handbook as exploration proceeds.

Finally one must remember that he who lives strictly by the rules, stagnates. Progress is attained only by knowing the rules, and then living dangerously beyond them.

ME-246 ON THE LIFT-AIR REQUIREMENT OF AIR CUSHION VEHICLES AND ITS RELATION TO THE TERRAIN AND OPERATIONAL MODE.

Fowler, H.S., Division of Mechanical Engineering, May 1979.

The optimization of installed power in a low-speed overland ACV is shown to depend heavily on the minimization of skirt/terrain interaction drag, which is in turn shown to depend critically upon lift-air supply.

The influence of hoverheight, terrain roughness and porosity, vegetation, and vehicle speed on drag is examined in the light of data from the CASPAR vehicles. An analysis is proposed by which the data can be reduced to give a lift airflow applicable to any vehicle having a segmented skirt, operating over a range of specified terrains.

Tentative values for these flow coefficients, together with associated drag coefficients, are given.

LABORATORY TECHNICAL REPORTS

National Aeronautical Establishment

LTR-FR-69	Leach, B.W.	Automatic Aeromagnetic Compensation. March 1979.
LTR-FR-70	MacPherson, J.I.	A Cumulus Cloud Seeding Experiment for Forest Fire Control – NAE Participation and Results for 1978. April 1979.
LTR-FR-72	Drummond, A.M.	A Comparative Assessment of Bacillus Thuringiensis Formulations for the NAE Flying Spot Scanner. April 1979.
LTR-LA-228	Irwin, H.P.A.H., Wardlaw, R.L., Wood, K.N., Bateman, K.W.	A Wind Tunnel Investigation of the Montreal Olympic Stadium Roof. June 1979.
LTR-LA-229	Savage, M.G., Muir, D., Irwin, H.P.A.H., Wardlaw, R.L.	A Wind Tunnel Investigation of Wind Velocities in Air Terminal Doorways. January 1979.
LTR-LA-230	Wickens, R.H.	A Streamtube Concept for Lift: With Reference to the Maximum Size and Configuration of Aerial Spray Emissions. February 1979.
LTR-UA-47	Crabbe, R.S.	A Gradient-Transfer Model for the Long Range Drift and Deposition of an Aerosol Cloud. January 1979.
LTR-UA-48	Orlik-Rückemann, K., Hanff, E., Anstey, C., Kapoor, K.	Feasibility Study of Dynamic Calibrators for Dynamic Stability Testing in Two Large Wind Tunnels. March 1979.
LTR-UA-49	Krzymien, M.	Determination of Fenitrothion Concentration in Ambient Air. April 1979.

Division of Mechanical Engineering

LTR-CS-199	Phan, C.S.	Generation of Random Samples Using Non-Parametric Methods. March 1979.
LTR-CS-201	Buck, Leslie	The Role of Proprioception in Locating Targets. June 1979.
LTR-HY-65	Funke, E.R., Mansard, E.P.D.	SPLSH – A Program for the Synthesis of Episodic Waves. April 1979.

LABORATORY TECHNICAL REPORTS (Cont'd)

Division of Mechanical Engineering (Cont'd)

LTR-HY-70A	Pratte, B.D., Willis, D.H. Pointe Sapin Model Study. May 1979.
LTR-HY-70B	Pratte, B.D., Willis, D.H. Pointe Sapin Model Study – Summary. May 1979.
LTR-LT-93	Coveney, D.B. The Cyclone Switch Heater for Railway Track Switches. Part II. Prototype Performance Evaluation. January 1979.
LTR-LT-95	Timco, G.W. A Chemical Survey to Determine Potential Dopants for a Model Ice Test Basin. January 1979.
LTR-LT-97	Timco, G.W. Impact Strength Tests on Ottawa River Ice. April 1979.
LTR-LT-98	Stallabrass, J.R. Icing of Fishing Vessels: An Analysis of Reports from Canadian East Coast Waters. June 1979.
LTR-SH-244	Murdey, D.C. Construction of a Plug for Manufacture of Albacore Class Sailing Dinghies. March 1979.
LTR-SH-256	Séguin, Y.P. Hardware Inferface for Ship Model Milling Machine to PDP 11/60 Computer. April 1979.

MISCELLANEOUS PAPERS

Buck, Leslie The Sensory Basis of Target Location. Quarterly Journal of Experimental Psychology 1979, 31, pp. 111-120.

Chan, Y.Y. Boundary Layer Developments on the Sidewalls of the NAE 2-D Test Facility. Presented at the 51st Semi-Annual Meeting of the Supersonic Tunnel Association, Lockheed-California Company, Rye Canyon Research Laboratories, Burbank, California, April 10-11, 1979.

Drummond, A.M. Experiments on Vortex Motion and Spray Deposition. Presented at Symposium on Long Distance Drift, U. of N.B., Fredericton, N.B., February 12-14, 1979. Published in Proceedings.

Dukkipati, R.V., Osman, M.O.M., Sankar, S. Application of Gyroscope in Contour Tracking. Presented at the Seventh Canadian Congress of Applied Mechanics, Sherbrooke, Vol. 1, May 27-June 1, 1979, pp. 423-424. Published in Proceedings.

Hanff, E.S. An Advanced Calibrator for Dynamic Wind-Tunnel Experiments. Presented at the ISA 25th International Instrumentation Symposium, Anaheim, California, May 7-10, 1979. Proceedings pp. 239-244.

Hawthorne, H.M. Surface Wear Characteristics of Some Hard Carbons. Presented at the 2nd International Conference on Wear of Materials (ASME), Dearborn, April 16-18, 1979. Proceedings pp. 528-535.

MISCELLANEOUS PAPERS (Cont'd)

Irwin, H.P.A.H. Centre of Rotation for Torsional Vibration of Bridges. Journal of Industrial Aerodynamics, Vol. 4, No. 2, April 1979, pp. 123-132.

Irwin, H.P.A.H., Cooper, K.R. Correction of Distortion in Fluctuating Pressure Measurements. Proc. 7th Canadian Congress of Applied Mechanics, Sherbrooke, Québec, May 27-June 1, 1979.

Irwin, H.P.A.H., Wardlaw, R.L. A Wind Tunnel Investigation of the Wind Forces on a Retractable Fabric Roof for the Montréal Olympic Stadium. Proceedings of the Canadian Society for Civil Engineers, 1979 Conference, Montréal, Québec, June 7-8, 1979.

Kekez, M.M., Lau, J.H., Lougheed, G.D., Savic, P. Micro-Particle Acceleration Behind Converging Shock Waves. 1979 IEEE International Conference on Plasma Science, Montréal, Québec, 4-6 June 1979, p. 102.

Kekez, M.M., Savic, P. Have We Reached the Limit to Power Transmission. 1979 IEEE International Conference on Plasma Science, Montréal, Québec, 4-6 June 1979, p. 82.

Laneville, A., Williams, C.D. Sur l'Effet de l'Echelle de la Turbulence sur la Trainée des Corps Non-Profiles. Proc. 7th Canadian Congress of Applied Mechanics, Sherbrooke, Québec, May 27-June 1, 1979.

Makomaski, A.H., Kekez, M.M. Beam Re-Entry into a Laser-Created Plasma. J. Phys. D: Appl. Phys., Vol. 12, 1979.

Murdey, D.C. Experimental Techniques for the Prediction of Ship Seakeeping Performance. International Symposium on Advances in Marine Technology, Trondheim, Norway, June 13-15, 1979. Published in Proceedings, Vol. 1.

Ohman, L.H. An Investigation of Possible Temperature Effects on Measurements in the NAE 2-D Test Facility. Presented at the 51st Semi-Annual Meeting of the Supersonic Tunnel Association, Lockheed-California Company, Rye Canyon Research Laboratories, Burbank, California, April 10-11, 1979.

Panarella, E., Gupta, R.P. Spherical Pinching in the REXIMPLO Experiment. 1979 IEEE International Conference on Plasma Science, Montréal, Québec, 4-6 June 1979, p. 102.

Ploeg, J. On the Modelling of Coastal Structures. Proceedings of the CSCE Regional Conference on Coastal Engineering, Kingston, Ontario, April 20-21, 1979.

Ploeg, J. On the Design of Large Rubble Mound Breakwaters. Proceedings of the Annual CSCE Conference, Montréal, Québec, June 6-9, 1979.

Pratte, B.D. Review of Flow Resistance of Consolidated Smooth and Rough Ice Covers. Proceedings of Canadian Hydrology Symposium: 79 – Cold Climate Hydrology, Vancouver, B.C., May 9-11, 1979.

Sacks, M.P., Lake, R.T., Cooper, K.R. Design of Tuned Mass Dampers for the LaPrade Heavy Water Plant. Proceedings of the Canadian Society for Civil Engineers Conference, Montréal, Québec, June 7-8, 1979.

Strigner, P.L. New ASTM Committee D-2 Technical Division P on Recycled Petroleum Products and Lubricants. Proceedings of the 3rd International Conference on Waste Oil Recovery and Re-use, 16-18 October 1978.

Strigner, P.L., MacLeod, D.M.*, Dunn, T.R.**, Shepp, L.P.*** Properties of USSR, USA and Canadian RR Car Journal Box Oils. ASLE Preprint 79-AM-6E-2, 34th Annual Meeting, St. Louis, Apr. 30-May 3, 1979.

Van Drunen, G.****, Liburdi, J.****, Wallace, W., Terada, T. Hot Isostatic Processing of IN-738 Turbine Blades. Presented at the 47th Meeting of the AGARD Structures & Materials Panel held in Florence, Italy on 26-28 September 1978. Published AGARD Conference Proceedings No. 256, Advanced Fabrication Processes.

Williams, C.D., Teunissen, H.W., Irwin, H.P.A.H. Lions Gate Bridge – Wind Measurements and Wind Tunnel Investigations. Proceedings 7th Canadian Congress of Applied Mechanics, Sherbrooke, Québec, May 27-June 1, 1979.

Williams, C.D. The Stability of Triangular Roadside Warning Devices – Wind Tunnel and Roadside Tests. Proceedings 7th Canadian Congress of Applied Mechanics, Sherbrooke, Québec, May 27-June 1, 1979.

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* Imperial Oil
** CN Rail
*** CP Rail
**** Turbine & Generator Div., Westinghouse Canada, Hamilton, Ontario

UNPUBLISHED PAPERS

Dayson, C. The Effectiveness of Wick-Fed Plain Bearings in Locomotives. Associate Committee on Tribology (ACOT) – CSME Tribology Seminar, Annual General Meeting, CSME, University of Sherbrooke, 31 May 1979.

Dukkipati, R.V. A Procedure for Axial Blade Stress Optimization. Seminar presented at the Department of Mechanical and Aeronautical Engineering, Carleton University, Ottawa, 10 May 1979.

Kalousek, J., Ghonem, H. The Wear of Rails and Wheels. Associate Committee on Tribology (ACOT) – SCME Tribology Seminar, Annual General Meeting of the CSME, University of Sherbrooke, 31 May 1979.

Kapoor, K., Hanff, E., Moulton, E. A New Apparatus for Oscillation-in-Roll Experiments. Presented by C. Anstey at the 51st Meeting of the Supersonic Tunnel Association, Valencia, California, April 10-11, 1979.

Schmitke, R.T.*, Glen, I.F.**, Murdey, D.C. Development of a Frigate Hull Form for Superior Seakeeping. Presented to the Society of Naval Architects and Marine Engineers, Eastern Canadian Section, Montréal, Québec, April 17, 1979.

PATENT

Hayes, W.F., Tanney, J.W., Tucker, H.G. Apparatus for Obtaining a Predetermined Flow Rate of a Fluid. British Patent 1,542,681, February 19, 1976***.

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* Defence Research Establishment Atlantic, Dartmouth, N.S.

** Directorate of Maritime Engineering and Maintenance, NDHQ, Ottawa.

*** Not previously reported – this patent has just issued but the British Patent Office uses the date of filing rather than the date of granting.